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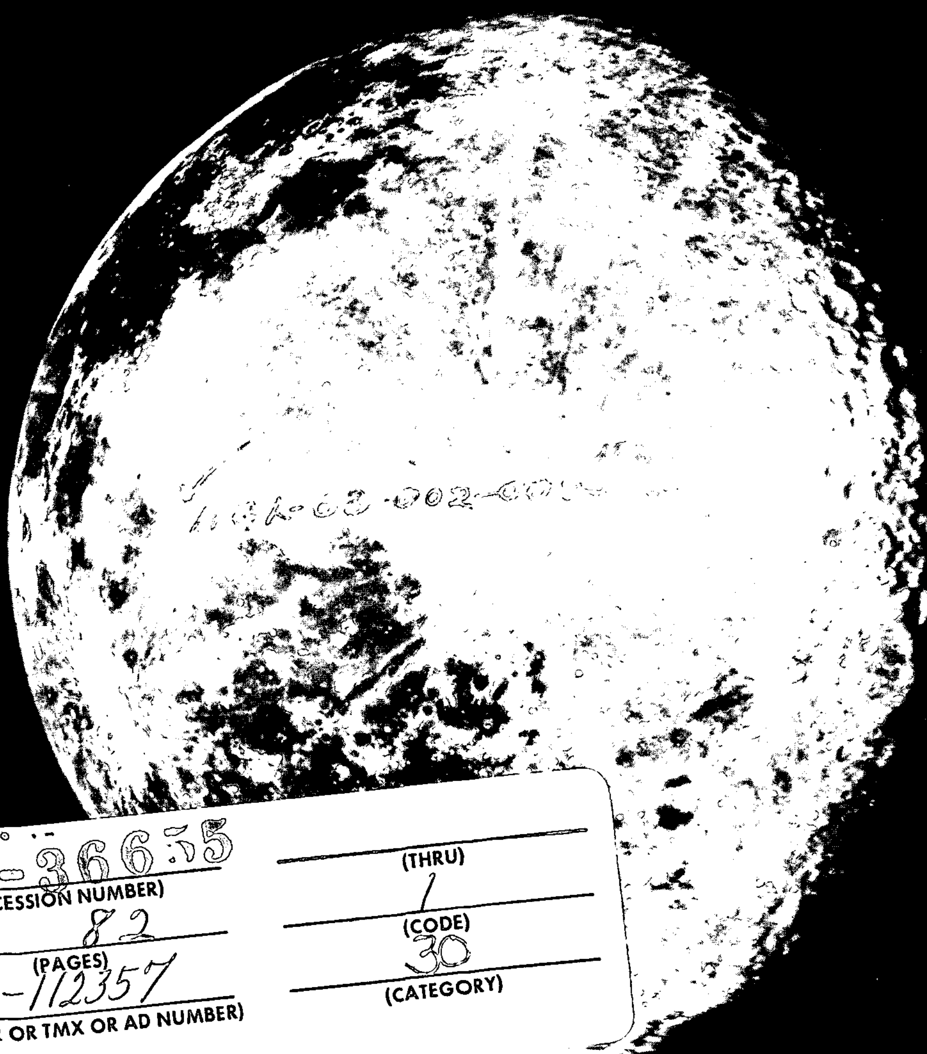

Volume 8 Part 3

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Communications of the Lunar and Planetary Laboratory

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No. 142 HIGH ALTITUDE SITES AND IR ASTRONOMY

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April 19, 1970

ABSTRACT

A reconnaissance is made of the comparative suitability of several U.S. mountain sites for IR astronomical observations. A systematic study of this kind had not been made. Table I is a working list of sites, some of which are described in more detail in the Appendices. The text develops some general criteria for intercomparison. The immense importance of a reduction in the water-vapor content is shown in Fig. 9. It is concluded that two types of sites can contribute: (1) dry sites at intermediate level, safe for manned scientific operations, allowing ready access, having IR and/or microwave facilities; and (2) the driest site(s) on which part-time manned operations are feasible (14,000-18,000 ft.), used during optimum conditions, in part by remote control from a laboratory-base some 5,000 ft. lower, and in part directly. The type-2 site needs cable car or aircraft transportation from the laboratory-base to the observatory. Airborne IR facilities are, of course, the third step in avoiding telluric absorptions. Studies are still needed for several potential sites on modes of access, frost points, cloud cover, and frequency of destructive winds. Calibrations of the free-atmosphere humidity data in Table I are made with direct measures from Pikes Peak, and less complete data on Mt. Lemmon, and some other sites. It is found that for large, isolated peaks the summit H_2O amounts may be somewhat more favorable than given in Table I (probably due in part to the radio-sonde data not recording the driest conditions and in part to subsidence of dry upper air replacing cold air on the slopes.) The tabular 5 percentiles are probably more closely 25 percentiles. The requirements of an IR observatory are developed in Sec. 3, including ways of reducing anoxemia; they differ from those of traditional optical observatories. Selected sites are described in Sec. 4 with additional information given in the Appendices. Fig 10 probably best epitomizes the complex interdependence of IR site selection problems.

1. *Introduction*

The present study was, in a sense, begun in 1961 with an aerial reconnaissance of mountains above 8,000 ft in Southern Arizona. The immediate purpose was to find an observatory site suitable for infrared spectroscopy and photometry (planetary and stellar), as well as for lunar and planetary photography and other solar system studies. The reconnaissance was followed in 1962 by ground inspections of a preferred location in the Catalina Mountains, NE. of Tucson, and by tests of image quality with 6- and 12½-inch telescopes. The seeing tests were made jointly by A. Herring and the writer, and will be described separately. They led to the final site selection of the Catalina Observatory, 36 miles NE. of Tucson. The aerial and ground studies were extended to Haleakala (1962–63), Mt. Agassiz (1963), Mauna Kea (1964), and Baja California (1968); aerial inspections were made of several additional sites.

This paper considers the concept of a *true high-altitude observatory,* with atmospheric water-vapor minimal during an acceptable fraction of the year. Both the IR (1-25μ+) and mm-region (0.3-3 mm) would clearly benefit from such a site; but excellence is achieved at the expense of hardships and dangers (low temperatures, low pressures, great difficulty of access). There is a point where aircraft must take over, though this point can be moved upward by appropriate technology (Sec. 3 and App. IV).

2. Water Vapor Above High Mountains

IR site surveys are concerned primarily with the atmospheric water-vapor distribution in three dimensions. A summary for the Northern Hemisphere was compiled by Gringorten *et al.* (1966), based on five years of radio-sonde measures. To indicate the nature of these data we are reproducing a few small sections of the AFCRL *Atlas* for two levels: 700 and 500 mb, corresponding to 10,000 ft (3 km) and 18,000 ft (5.5 km), respectively; (cf. Figs. 1-4). Earlier results on the vertical distribution of water vapor for both hemispheres were compiled as charts giving seasonal averages (Bannon and Steele, 1960).

The constant dew-point curves over the Western U.S. run (with some exceptions) roughly EW., for both 500 and 700 mb, with an average latitude separation of roughly 26° for 10°C, measured along the 110° W. meridian starting around 30°N (and excluding July). (The "dew point" plotted by Gringorten *et al.* is defined by a formula valid in the range where dew points (not frost points) exist and is extrapolated beyond. This "dew point" is readily related to absolute content through their Table I). For a dew point of −35°C, a difference of 5°C (or 13° lat.) corresponds to a factor of about 1.6x in the moisture content. For water vapor this corresponds to a vertical displacement of about 3,000 ft, so that for equal H_2O content, high-latitude sites need not be so high. For equally-high mountains and dec. 0°, the optimum geographic latitude (with allowance for the secant law) would, with the above gradient, be 65°N; for dec. −30°, 35°N. Ignoring the logistics, Mt. McKinley, at high latitude *and* altitude, would be the optimum ground-based site for stars and planets N. of −10° dec.

The humidities for specific mountains may be estimated by interpolation from the AFCRL *Atlas;* but the results may not always be valid. Mountain chains (e.g. the Sierra Nevada) cause *orographic up-lift* of low-altitude moist air. Isolated peaks (Mauna Kea; Mt. Shasta, California; Pikes Peak, Colorado; Mt. Agassiz and Mt. Lemmon, Arizona) are better, since they more nearly resemble probes in the free atmosphere.

Two further effects will cause deviations. In studying the air flow around Mauna Loa in Hawaii in 1963 (summit 13,700 ft = 4.2 km), the writer noted the strong downdraft at the 11,200 ft (3.4 km) level of the U.S. Weather Bureau Station, 10-15 mph, reportedly depending on the season. At the Station, on the North slope, the down-flow was Northward, bucking the 15-20 mph Trade Wind from the NE. The downdraft was clearly due to the *radiation cooling* on Mauna Loa, an effect that would be less on smaller mountains. The downdraft will somewhat reduce water vapor at the summit, since the air will be replaced in part by higher air parcels which are drier. This subsidence resembles the flow resulting from a near-stationary barometric high, with outward flow near the surface and replacement at altitude by upper-atmospheric dry air (this effect is included in the radio-sonde averages).

An opposite effect is the increase of daytime moisture content of surface air due to *snow fields and glaciers*. It resembles the effect of a large lake at lower altitude. This tendency toward saturation will be reduced if the summit is a *narrow peak,* enveloped in constantly-renewed air from the free atmosphere; and at night by the downdraft. By the orographic and solar-radiation effects, high mountains are during the day frequently enveloped in clouds. During the night the updraft due to solar heating is replaced by a downdraft due to cooling and the peak may then be completely clear. (High altitude snow fields cool steeply at night due to the near-transparent atmosphere and the high IR emissivity of ice.) *Thus, at the summit, the free-atmosphere humidities will roughly apply during clear nights, or even improved upon by subsidence,* except when strong winds cause the orographic up-lift to predominate. How often this occurs must be determined in each case; the installation of appropriate temperature and frost-point devices, equipped with telemetry, should precede any decisions on telescopic installation. A typical airflow pattern for Pikes Peak is illustrated in Appendix III.

On the basis of the *AFCRL Atmospheric Humidity Atlas for the Northern Hemisphere,* we have computed the total water-vapor content in a vertical column above 30 mountain sites, listed in Table I, considered representative and including extremes. The following assumptions were used: (a) that free-atmosphere conditions pertain at the summit levels, so that direct interpolations for the dew point may be made from the *Atlas* (i.e. that relatively quiet nighttime conditions are not infrequent); and (b) that the scale height of the water-vapor distribution above the summit is the average tropospheric value, 1.6 km* (Kuiper *et al.* 1967). Two values were used

*For the *lower* troposphere the value may be more nearly 2.2 km (Hann derived 2.3 km at the turn of the century). For the lowest stations the actual H_2O amounts may therefore be 2.2/1.6 times larger than given in Table I; cf. App. II.

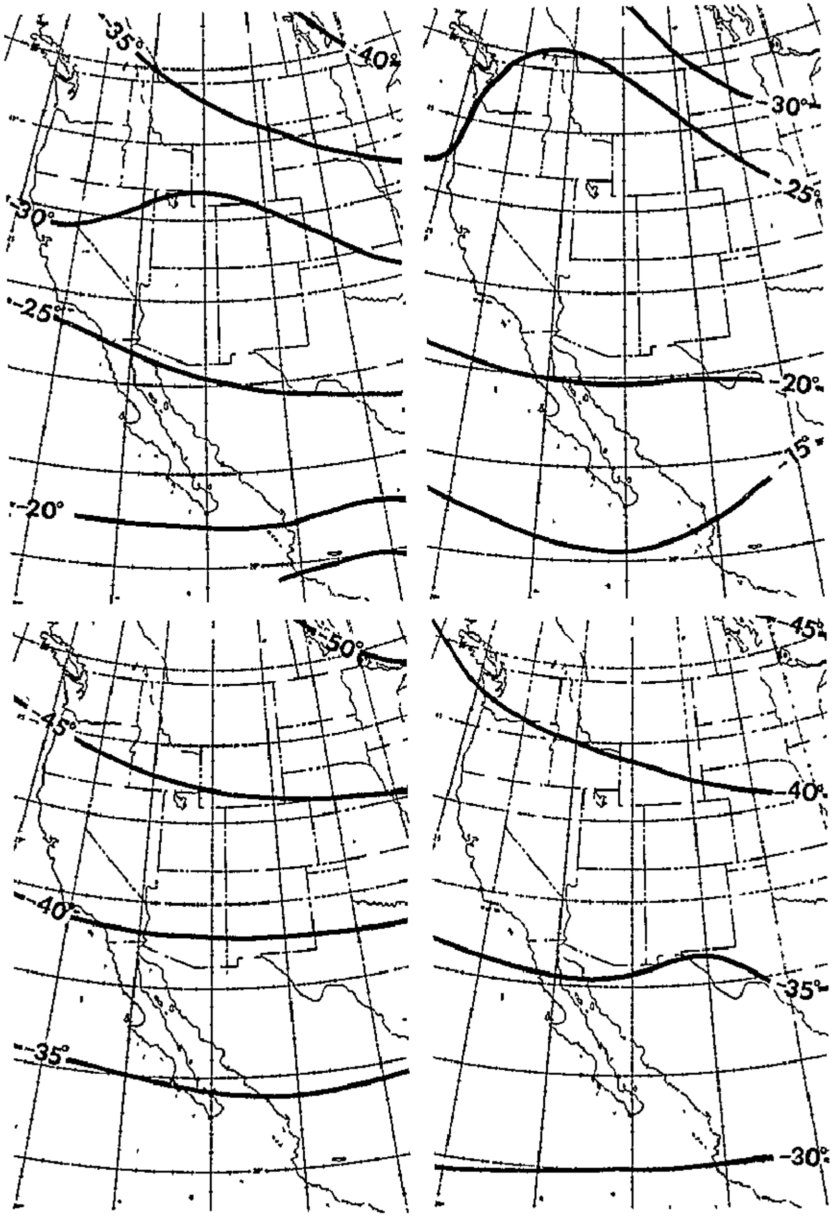


Fig. 1 Dew points for the 700 *(above)* and 500 *(below)* mb levels; *left* 5 percentile, *right* 25 percentile; for the Western U.S., for January (after Gringorten *et al.*, 1966).

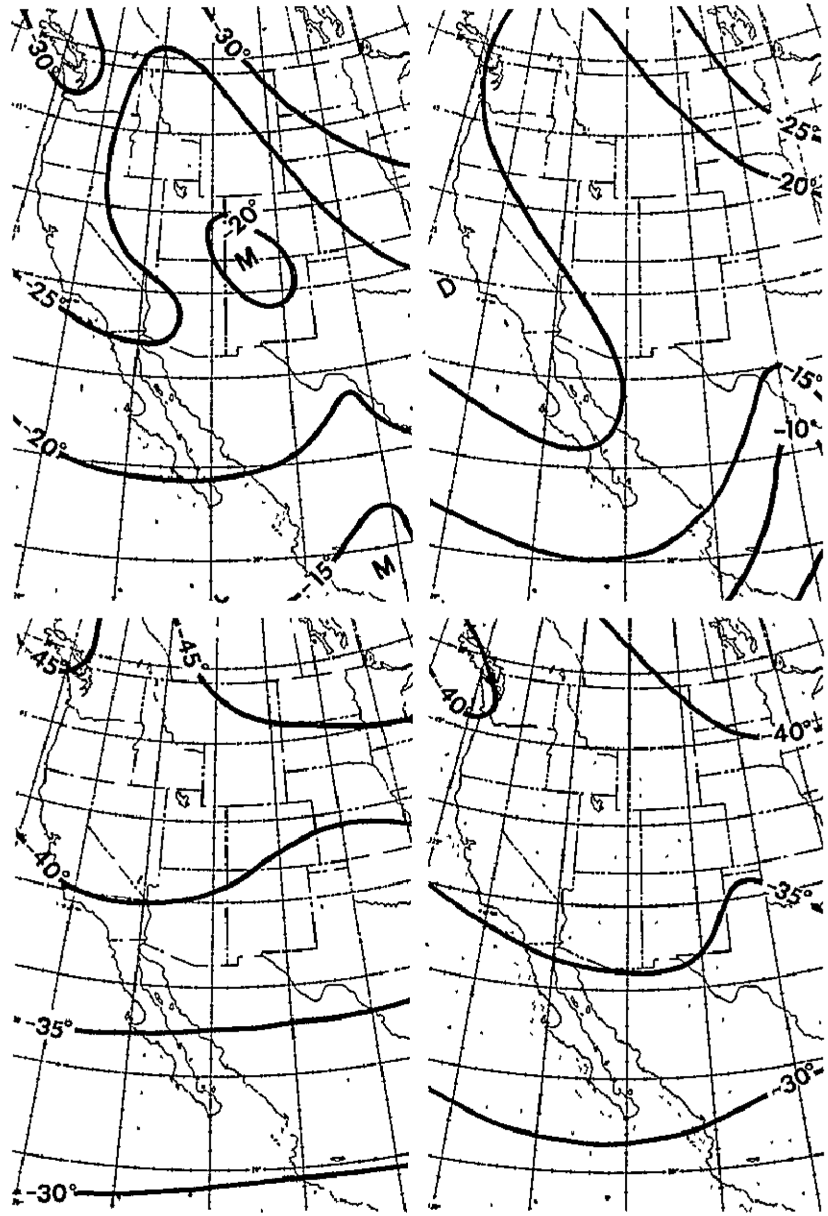


Fig. 2 Same arrangement as Fig. 1, for April. (Gringorten *et al.*, 1966).

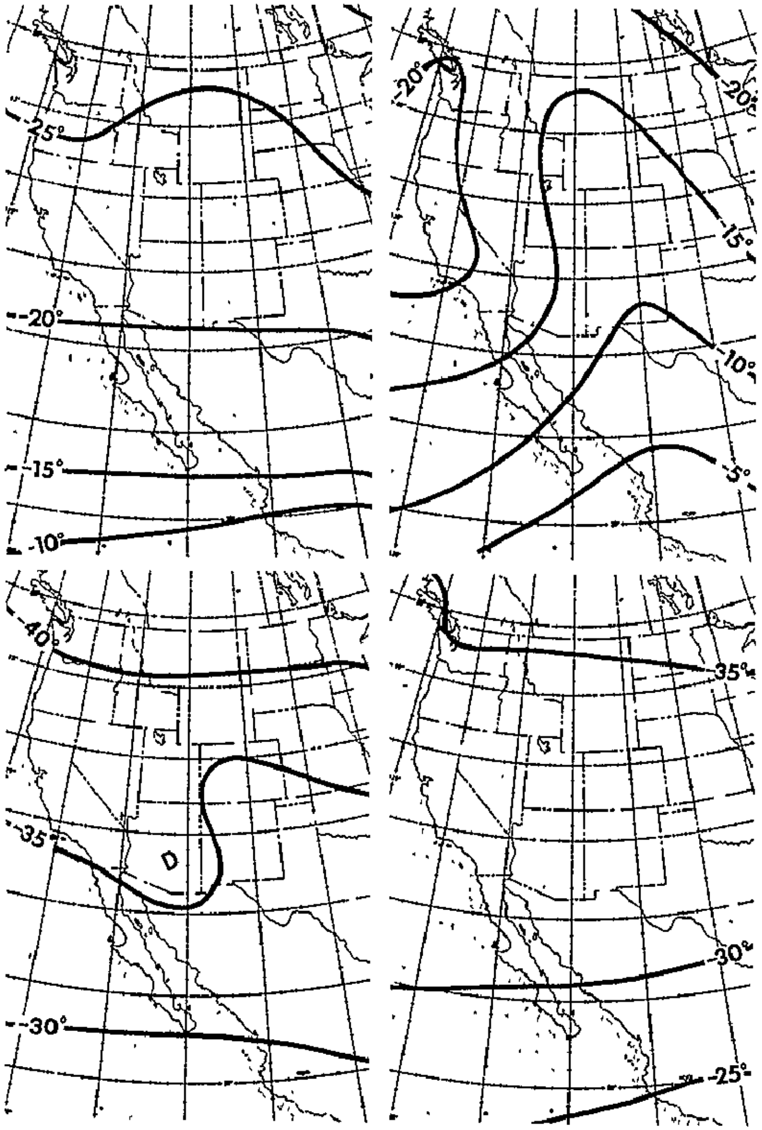


Fig. 3 Same arrangement as Fig. 1, for October. (Gringorten *et al.*, 1966).

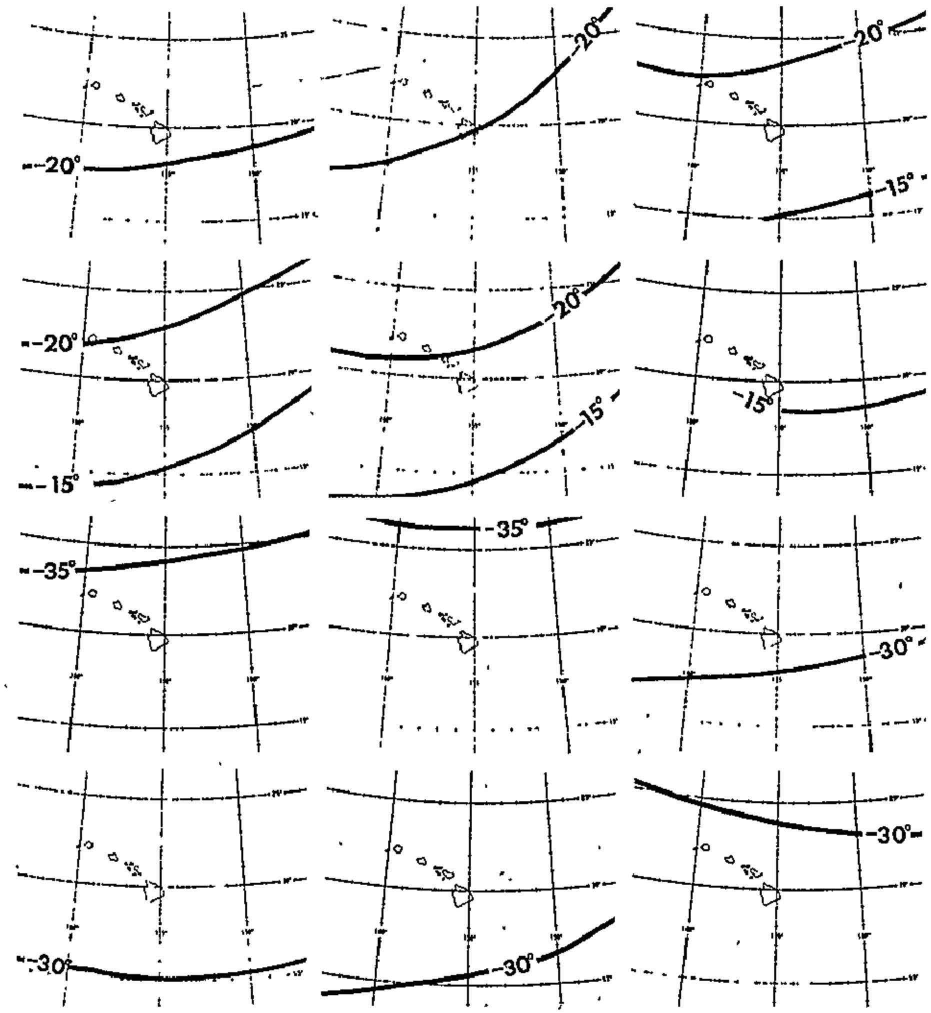


Fig. 4 Dew points for January *(left)*, April *(center)*, and October *(right)*; *top* to *bottom* 700 mb, 5 and 25 percentiles; 500 mb, 5 and 25 percentiles; for region of Hawaiian Islands. (Gringorten *et al.*, 1966).

TABLE I

Precip. H_2O in Vertical Column (mm)

Site	Lat (N)	Long	Elevation Ft	Elevation M	p (mb)	Access*	Precip.	Snow†	January 5%	January 50%	April 5%	April 50%	July 5%	July 50%	October 5%	October 50%	25% ± (9 Mo.)
Palomar Obs. (Calif.)	33°21′	116°52′	5600	1706	825	A	24	36	1.8	3.4	1.9	4.4	3.5	9.5	2.6	6.1	2.1
National Radio Obs.	38°26′	79°50	2700	823	920	A	44	80	1.2	4.3	2.6	8.0	12.	20.	3.4	10.	2.4
Kitt Peak Nat'l Obs.	31°58′	111°36′	6750	2064	789	A	12	4	1.7	4.4	1.8	3.7	5.5	10.9	2.3	7.1	1.9
Catalina Obs. (Ariz.)	32°25′	110°44′	8450	2580	740	A	12	5	1.1	2.9	1.4	3.0	5.1	9.7	1.9	5.5	1.5
Mt. Lemmon (Ariz.)	32°26′	110°47′	9190	2800	720	A	12	5	1.0	2.7	1.3	2.8	5.0	9.1	1.8	5.0	1.4
Humphreys Pk. (Ariz.)	35°21′	111°41′	12633	3852	629	O	24	60	0.57	1.4	0.7	1.6	1.7	4.8	0.94	2.1	0.74
Mt. Agassiz (Ariz.)	35°20′	111°41′	12356	3770	636	A *	24	60	62	1.5	.8	1.7	2.0	5.2	1.0	2.3	0.81
Charleston Pk., Nev.	36°16′	115°42′	11920	3635	647	O *	12	10	.56	1.5	.57	1.85	1.85	3.1	1.1	2.6	0.74
White Mt., Calif.	37°38′	118°15′	14242	4340	590	O *	12	30	.44	1.1	.49	1.2	1.1	1.9	0.7	1.3	0.54
Barcroft Lab. (White Mt.)	37°35′	118°15′	12500	3510	632	A	12	30	.59	1.4	.66	1.6	1.4	2.4	.8	1.6	0.68
Wheeler Pk., Nev.	38°59′	114°19′	13058	3980	618	T *	12	60+	.47	1.2	.65	1.5	1.35	3.1	.8	1.9	0.64
Delano Peak, Utah	38°22′	112°22′	12173	3712	640	T *	16	60+	.57	1.4	.83	1.7	1.6	4.3	.95	2.4	0.78
Mt. Peale, Utah	38°.4	109°.2	12721	3880	626	O	24	60+	.48	1.3	.90	1.6	1.6	4.5	.93	2.3	0.77
Mt. Nebo, Utah	39°49′	111°45′	11871	3620	648	T *	16	50	.57	1.5	1.0	1.9	1.7	4.4	1.0	2.5	0.86
Mt. Timpanogos, Utah	40°23′	111°39′	11750	3580	652	T *	32	100	.54	1.5	1.0	2.0	1.7	4.5	.96	2.6	0.83
Kings Pk., Utah	40°47′	110°22′	13528	4130	606	O	40	150:	.40	1.1	0.67	1.4	1.3	3.6	0.75	1.8	0.61
Pikes Pk., Colo.	38°50′	105°2′	14110	4300	593	(A)*	24	100	.40	1.0	.7	1.3	1.6	4.2	.81	1.9	0.64
Mt. Shasta, Calif.	41°25′	122°12′	14162	4317	592	O *	80	100+	.35	1.0	.47	1.2	0.93	1.7	.64	1.35	0.49
Mt. Rainier, Wash.[1]	46°51′	121°46′	14150	4313	592	O *	96	400+	.38	0.95	.39	1.2	.88	1.6	.54	1.4	0.44
Mt. Fairweather, Alsk.	58°54′	137°31′	15320	4670	566	O *	32	200:	.16	0.6	.23	0.6	.7	1.6	.25	0.8	0.21
Mt. McKinley, Alaska	63°05′	150°59′	20320	6200	459	O *	16	100	0.07	0.15	0.09	0.20	0.24	0.6	0.09	0.24	0.08
Mauna Kea, Hawaii	19°.8	155°.5	13800	4215	600	A	16	+	1.2	1.5	1.0	1.8	1.3	2.0	1.2	2.3	1.1
Baja California, Mex.	31°.0	115°.6	9280	2830	717	(A)	—	—	1.2	2.6	1.35	2.8	3.5	8.2	1.9	4.7	1.5
Popocatepetl, Mex.	19°.0	98°.6	17887	5450	509	O	—	—	0.61	1.0	0.79	1.4	1.9	2.8	0.81	2.7	0.74
Road terminus[2]	19°.0	98°.6	15500	4730	560	A	—	—	.9	1.7	1.1	2.1	2.9	4.1	1.25	4.1	1.1
Mt. Bolivar, Venez.	8°.6	71°.1W	16427	5000	540	A	—	—	.6	1.6	1.1	1.7	1.5	2.8	1.6	3.5	1.1
Jungfraujoch, Swit.	46°.5	8°E	11500	3500	658	A	—	—	.52	1.5	0.6	2.0	1.4	4.1	1.1	2.7	0.74
Mt. Blanc, France	45°52′	7°E	15782	4810	554	O	—	—	0.25	0.9	0.28	0.9	0.6	1.8	0.42	1.3	0.32
Tenerife, Canary Is.	28°.3	16°.7W	12000	3660	645	(A)	—	—	1.1	3.4	1.2	2.2	2.3	3.7	1.9	3.7	1.4
Zelenchukskaya[3]	43°50′	41°36′E	6830	2080	788	A	—	—	1.9	4.1	2.3	4.2	5.3	9.6	2.2	5.8	2.1
Mt. Ararat, Turkey	39°.7	44°.3 E	16945	5165	529	O	—	—	0.42	1.0	0.59	1.3	0.9	2.3	0.7	1.6	0.57
Mt. Everest	28°.0	87°.0 E	29002	8840	315	O	—	—	0.09	0.13	0.09	0.16	0.6	1.7	0.17	0.24	0.12

* Accessible by road (A), trail (T), not (O).

1) Point Success: summit crater unsuited.

2) Road to 15,500′ = 4730 m, where snow-covered deep cinders begin.

3) Future site of 6-meter telescope.

† These interpolated chart figures must apply to *wider* areas than the summits. (E.g., Catalina Obs. summit figures are around 40″; cf. Appendices for some other sites.)

for each site, based on the 5 and 50 percentiles: i.e. the "average best" and "median" values.

Exceptional conditions will be better since (a) the radio-sonde equipment does not record relative humidities below 20-35% (cf. App. II) and there the AFCRL *Atlas* uses an average; and (b) on quiet nights there will be subsidence over the summit. The sites may be readily intercompared through the last column of Table I which lists the average of the 5% January, April and October columns. It is, on the basis of the Pikes Peak and Mt. Lemmon data, our best estimate of the 20-25 percentiles for the 9 dry months of the year (the 3 summer months excluded). *The driest nights will be better than these values by a factor of about 2-3.*

In summary, because of orographic effects (cf. App. III, Fig. 30) and the different radiation regimes of day and night, the quantities in Table I must be used with caution even for nighttime conditions. For one high site (Pikes Peak, App. III) the values of Table I can be tested and they appear, if anything, conservative.

3. *Requirements for IR-Microwave Observatory*

The first condition for a high-altitude observatory is *low atmospheric water-vapor content.* This determines what can be achieved spectroscopically in the regions 1-6μ, 7-8μ, 16-25μ+, and longward of 300μ. These regions open up beautifully when the water vapor goes down and new parts of the spectrum can be explored. At very low frost points almost the entire IR becomes accessible. Also, because of the presence of small amounts of water vapor on Venus, Mars, Jupiter, and late-type M stars, both the telluric H_2O content and its pressure must be held to a minimum even if the Doppler shift is used to separate the sources. *Good seeing* (image quality) is also very important, since the size of the stellar image determines the size of the IR detector required and thus its sensitivity. A third criterion often discussed is low *sky-noise,* considered particularly important in the 10μ region. However, Dr. Low has pointed out that for telescopes up to 1.5 meters aperture, used by him at the Catalina Observatory, he has been able to eliminate sky noise at 10μ routinely to below the level of the photon noise, almost regardless of conditions. Other observers have reported large *systematic* differences in sky noise between different observatories. Certainly, at any *one* site, large variations in sky noise do occur depending on meteorological conditions, such as mixing of different air masses. These variations are not unlike those found optically (0.5μ) in "seeing," with different observatories having also systematic differences. A better understanding of these differences is desirable and high-altitude sites should be tested for 10μ sky noise.

The *transportation problem* deserves special consideration. Regardless whether the approach is by road, cable car, helicopter, or light airplane, there will be a premium on *low precipitation in the area* and a maximum freedom from clouds. Fig. 5 shows the distribution of annual precipitation over the Western U.S. (U.S. Dept. of Commerce, 1968). The contours of Fig. 5 together with the coordinates give the precipitation column of Table I. Since the contour values increase by steps: 8, 12, 16, 24, 32, 48, 64, 80, 96, etc., the actual values may be up to 1.5x higher than listed. The mean annual snowfall for the Western United States is shown in Fig. 6 (U.S. Dept. of Commerce, 1968). The Mt. Rainier area has over 400 inches, the Shasta area over 100 inches.

In drawing conclusions from Table I, *two limiting cases* remain relevant: (1) the traditional astronomical observatory, with its conveniences (near city, university, airport; good access road, utilities; nearby support facilities, shops, coolants; adequate housing), but (except for the 10μ window) relatively poor IR-mm atmospheric transmissions; (2) the aircraft, flying at 40, or 50,000 ft with a residual of 8-2 microns of precipitable water vapor overhead, with small-to-modest-aperture equipment (12 inches 1967–72, 36 inches after 1972), limited guidance accuracy, limited observing runs (2-4 hours per flight, depending on equipment), with finite risks to personal safety (brittle windows, open port, etc.). Or else, the high-altitude balloon, with non-standard equipment adapted to the low ambient pressure and temperatures, with the usual command, guidance, and telemetry problems. In a given project, airplane flights can be made at the rate of two or three per week; balloon flights, at the rate of two or three per year. The cost in either case is about $\$10^4$ per flight, not counting preparations by the scientific team; while the capital outlay for base facilities may be $\sim \$10^6$.

The *efficiency* of IR observation from aircraft, within limitations stated, is close to 100%. On some 30 flights on NASA's CV-990, the writer obtained definitive scientific results on all but one or two preparatory test fights. Ballooning involves greater risks, including the possibility of damage to or loss of equipment; but allows observation for several hours at 120,000 ft (36 km) and above, not other-

Fig. 5 Distribution of Annual Precipitation over Western U.S.

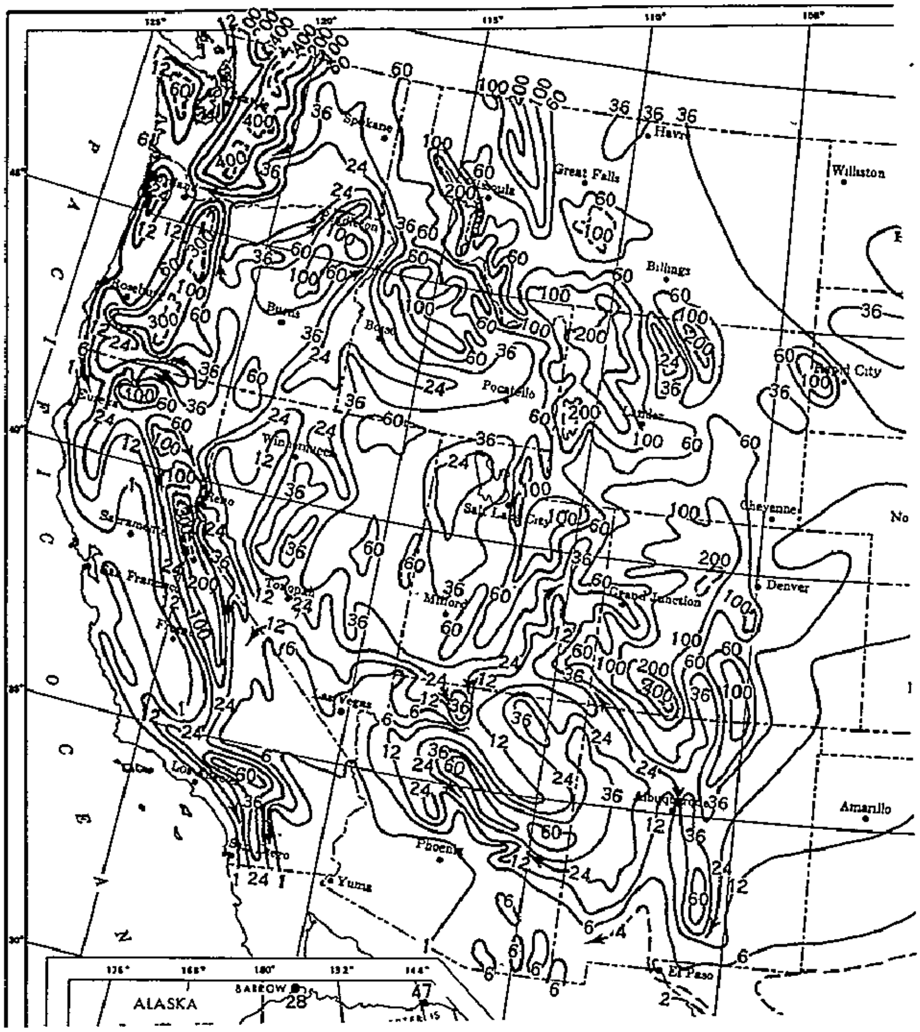


Fig. 6 Mean Annual Snowfall of the Western U.S.

wise achievable on modest budgets; and involves no risk to scientific personnel. The degree of efficiency of observatory operations is too well known to require much comment here. Among the merits of an observatory are: large telescope with good image quality, possibility of extensive preparations of attachments on the spot, and accessibility. However, because of the complexities of the lower atmosphere, there are interruptions and the quality of the data is variable.

In considering a high mountain site the needs of microwave (mm) astronomy must be included. Some measurements may be made from aircraft with small telescopes, in spite of the low resolution; but most problems require larger telescopes which cannot be flown from aircraft. The absence of destructive winds will be a prime criterion.

The sites listed on Table I are of two kinds: (a) those which are or can be made accessible by a road on a year-around basis and would be operated much like optical observatories; and (b) those for which an access road or tunnel and its year-around maintenance would be too costly. For the latter group *cable cars* can be used at a minor fraction of road or tunnel expense; or, aircraft or helicopters. The conveniences of an optical observatory will be lacking and continuous use cannot be assumed, any more than from aircraft or balloons. One may install automatic equipment for alerting the team at the base that observing conditions are improving (cloud cover, wind velocity, frost point). Efficient transportation to the summit must then exist. To illustrate: the Jungfraujoch Observatory, at which the two important Liège Atlases of the IR solar spectrum

Fig. 7a Cable car to Pic du Midi Observatory.

Fig. 7b Cable car to Mt. Bolivar above Mérida, Venezuela.

have been recorded, had during the data runs about three clear days per month. It is reached by cog railway and tunnel and has no convenient base nearby. Only the runs with the lowest humidity will be published. Because of unavoidable hardships at high altitude, required personnel presence must be minimized, which means an alert system and *good transportation from a base equipped with laboratory facilities.* Aircraft have limitations and hazards, but may be the only way feasible at very high altitude. Cable cars have been the safest regular means of transportation at moderately high altitudes. Chair lifts are used for heavier traffic (skiers), but are not safe in bitter cold and strong winds (even a 20 min. power failure can be fatal to occupants). A cable car installation is also capable of *moving items of several tons and almost indefinite dimension* to the summit (by replacing the cabin with a platform). The cost of a cable car installation goes up with roughly the cube of the pay load; there is no known limit. The cable car serving the Pic du Midi Observatory has safely operated for over 30 years (Fig. 7a). If the elevation difference with the base is much above 1 km, more than one run is used in sequence; e.g. four between Mérida and Pico Espejo (15,867 ft, 4,840 m), near the summit of Mt. Bolivar (16,427 ft, 5,000 m) in Venezuela (Fig. 7b).

The inaccessible sites in Table I that appear to

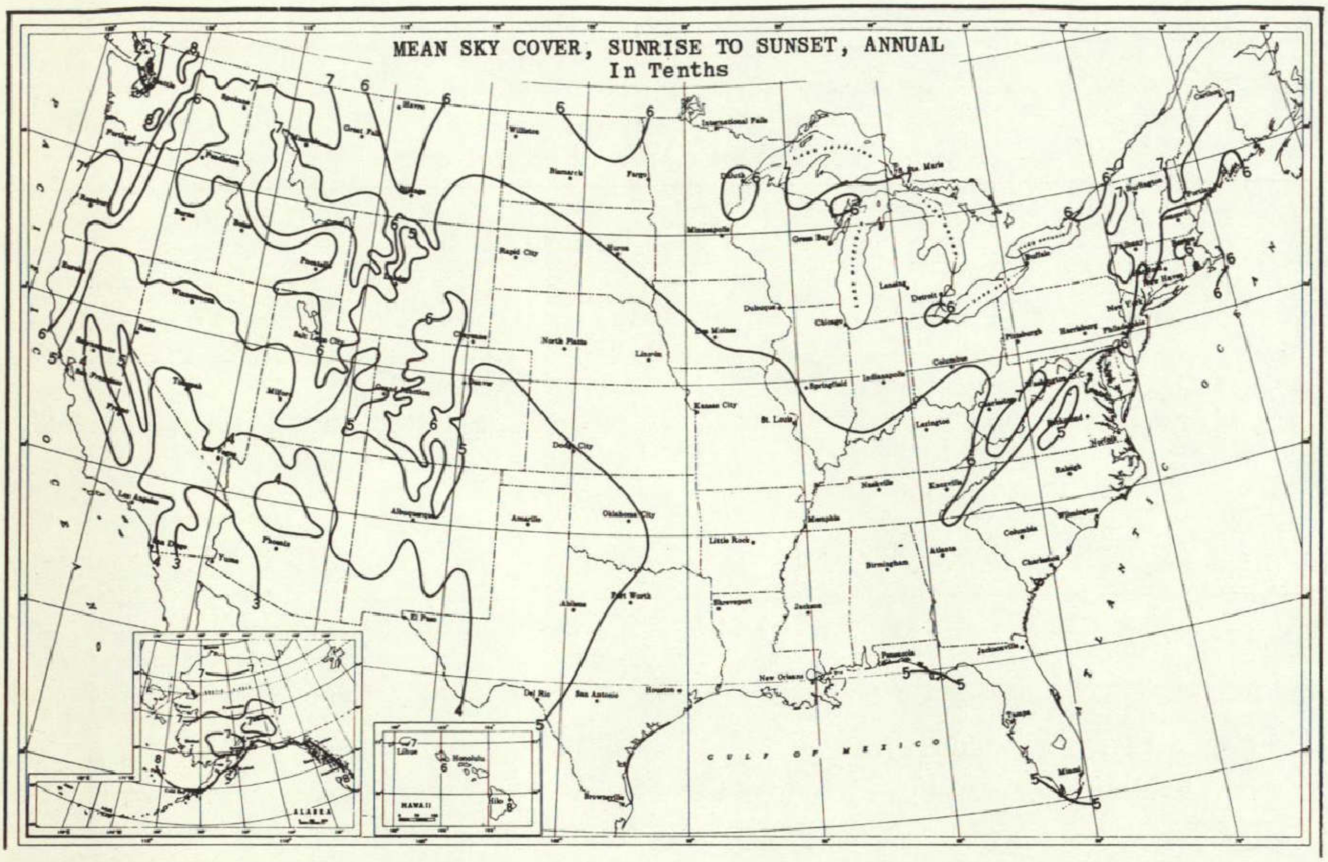


Fig. 8 Distribution of daytime sky cover over Western U.S.

merit further study are marked by asterisks in the "Access" column; several can probably be dropped after initial comparisons have been made. The criteria are: (a) nighttime temperature, frost point, percentage of clear skies, annual precipitation both at summit and on slopes; (b) feasibility and approx. cost of cable car installation (presence of exposed rock, continuity of slope, courses of avalanches and glaciers); (c) alternative support by helicopter; (d) feasibility of observatory construction (presence of exposed rock for foundations, snow load; small-unit designs may be required, cf. (b) and (c); (e) good seeing. (Criterion (e) requires studies of the flow pattern around the summit.)

The amount of clear weather may be estimated from the Weather Bureau charts of fractional daytime sky cover; cf. Fig. 8 for the Western U.S. The nighttime sky cover over high mountains is likely to be more favorable.

Operation around 14-18,000 ft is possible under strictly controlled conditions; regular use of oxygen is important since, without it, night vision and other biological functions are seriously impaired. Astronomers should be adapted a few days beforehand to 8-10,000 ft elevation at the base-laboratory, and only persons admitted to high altitude who have passed a heart examination and stood up well at the 9,000 ft level. The body needs oxygen for work, keeping warm, and digestion of food. An overload on any one, or in combination, can be serious or fatal (e.g. the use of alcohol is dangerous since it competes for oxygen). Electrically-heated suits must be used for nighttime operations (the writer has never felt so completely chilled as during open-air tests on Mauna Kea).

The following data on loss of human efficiency vs. duration of high altitude exposure are of great interest (Armstrong, 1943, p. 275, Table 22).

Exposure	Loss of Efficiency					
(hours)	0%	20%	40%	60%	80%	100%
1	9*	12	14	16	18	20
6	9	12	14	15	16	18
18	9	11	13	14	15	16

* Elevations in 1,000 ft; 100% = unconsciousness.

This would show that limited manual operation up to 17,000 ft is possible with the observers returning to the base-laboratory after an hour or so; and that all-night operations are possible up to about 14,000 ft, provided that the observers thereupon return to the base for their rest. This checks with my personal experience on Mauna Kea, with Hale Pohaku (9,200 ft) used as a base (no extra oxygen was ever used in our 1964 operations). "In contradistinction to the relatively mild or even total absence of subjective symptoms while at high altitude, the after effects may be quite severe." . . . "Prolonged passive exposures to altitudes of less than 9,000 feet or short exposures of a few minutes to altitudes of 18,000 to 25,000 feet, if promptly and completely relieved, are usually entirely free from distressing after effects." . . . "It has recently been found that a moderate degree of oxygen-lack affects night vision to the extent that at 9,000 feet such vision is reduced to about half and at 16,000 feet without oxygen the eye may be as much as ten times less sensitive as when adequate oxygen is breathed." . . . "Exposure to an altitude of 15,000 to 18,000 ft for a period of 2 to 6 hours may be followed by a very severe intractable headache, nausea, vomiting, dizziness, mental confusion, muscular weakness, and even complete prostration." . . . "Chronic altitude sickness may develop from repeated exposure to altitudes as low as 12,000 feet" . . . (Armstrong, *op. cit.*)

Reference is made also to the recent summaries (Hock, 1970, and Baker, 1969), the first concerned, among others, with the maximum relatively-safe altitude for human existence: "The highest inhabited settlement in the world is a mining camp at 17,500 ft (5330 m) in Peru." . . . "The miners rebelled against living in a camp built at 18,500 ft, complaining that they had no appetite, lost weight, and could not sleep. It seems, therefore, that 17,500 ft is the highest altitude at which even acclimatized man can live permanently." (Hock, p. 53) . . . "As the climbers moved up from 13,000 to 19,000 ft and beyond, the number of red cells in the blood increased continuously for as long as 38 weeks." (*op. cit.* p. 55) . . . "The physiological adjustments of the permanent mountain dwellers are similar in kind to those developed by sojourners in the mountains after a year of residence there. Furthermore, even mountain natives sometimes lose their acclimatization to high altitude and incur soroche (chronic mountain sickness), which is characterized by extreme elevation of the relative number and mass of red cells in the blood, pulmonary hypertension, low peripheral blood pressure, enlargement of the right lobe of the heart and ultimately congestive heart failure if the victim remains at high altitude." (*op. cit.* p. 56).

It may be added that the FAA regards 8,500 ft the safe ceiling for unpressurized aircraft, with the 10,000-ft level limited to about 30 min. duration. The NASA CV-990 rings a bell when the cabin pressure drops below the 9,500-ft mark. Many persons, two prominent astronomers among them, have suffered heart attacks at 9,000-10,000 ft. Experience at the High Altitude Solar Observatory at Climax, Colorado, 11,100 ft, confirms appreciable altitude effects on the observers, even though they work in daytime in full sunlight. All this does not imply that one should not observe above 10,000 ft; rather that then a new set of rules will apply, the more urgently the higher one must go and the longer one must stay.

Supplementary comments based on the most recent medical experience are quoted in App. IV.

The practical needs of IR astronomy will probably be met by a *combination of facilities:*

(1) Sites accessible by road (except during major storms), with absence of destructive winds ($>$ 120 mph), having *at night* during an acceptable fraction of the year amounts of atmospheric water vapor of 0.5-1.0 mm; suitable for use of extensive IR and microwave facilities; accessible through a nearby airport and with adequate base facilities (offices, lab, shops, coolants, etc.).

(2) One or two sites having night temperatures $< -35°C$ (i.e. very low absolute humidities) during an acceptable fraction of the year; equipped with a modest-size IR telescope with stationary focus, probably placed largely underground, suitable for Fourier Transform Spectroscopy and broad-band energy measurements; serviced by cable car or aircraft from a laboratory-base some 5,000 ft lower, *with an increasing proportion of IR operations conducted by remote control from the base* (after having been started manually, if needed, by staff returning to base afterward, with observations monitored through a cable link, terminating the runs by remote control; and with the staff resting at the base). This will require development of semi-automatic astronomical equipment.

(3) From aircraft or balloons, at 50,000 ft (15 km) and above, measurements of energy curves and Fourier Transform Spectroscopy of brighter sources.

Mauna Kea, Mt. Agassiz and Mt. Lemmon fall into Category 1, with Mauna Kea equipped with an 88-inch telescope; and Mt. Lemmon partly developed, having an altitude that poses no problems to most persons even if adapted to sea-level conditions. Mt. McKinley, Mt. Logan (App. IV), Mt. Shasta, and possibly Pikes Peak fall into Category 2, with further technical and meteorological data needed to establish priorities. The efforts required to develop sites of Category 2 must be balanced against the capabilities and budgets of Category 3. It may be assumed that most IR operations require not one observer, but often a team of three; and that one should never ascend to high altitude alone.

Orographic effects may cause cloud caps or cloud trains near the summit where lower altitudes would be clear. This is one reason why optical and IR astronomical facilities are best separated, at different elevations; the other being the obvious increased strain and reduced efficiency of observers at high altitude. On nights of low humidity (those of chief interest to IR astronomy) the summit will be clear.

The potentialities of the two types of IR observatory, as compared to the airplane, are illustrated by the laboratory spectra reproduced in Fig. 9, kindly obtained for this paper by Dr. D. P. Cruikshank and Mr. A. Thomson. The assumptions are based on the 25 percentiles of Table I, last column.

IR Observatory, Type 1 (e.g., Mt. Lemmon, 1.3 mm H_2O, 720 mb). Since our laboratory runs were made at p = 70.5 cm Hg = 940 mb, and since strong absorptions increase roughly as $\sqrt{pN}$, the water vapor in the path was decreased to 1.0 mm (cf. Fig. 9a).

IR Observatory, Type 2a (e.g., Mt. Shasta in January), 0.35 mm H_2O at p = 592 mb or 0.22 mm at p = 940 mb (cf. Fig. 9b, which has 0.19 mm); this would be at the same time the *best* condition to be expected on Mt. Lemmon.[*] A lunar spectrum taken with the 61-inch Catalina Telescope (el. 8,250 ft) reproduced in Fig. *9e* is intermediate between *9a* and *9b*.

IR Observatory, Type 2b (Mt. McKinley, Alaska, or Mt. Logan, Yukon), about 0.10 mm H_2O at 459 mb or 0.05 mm H_2O at 940 mb (cf. Fig. 9c, having 0.045 mm).

Aircraft at 40,000 ft. with 0.006–0.010 mm H_2O (typical NASA CV-990 flights), (cf. Fig. 9d, which has twice, 0.014 mm).

In judging the traces a useful criterion is to demand that the telluric absorptions be less than 0.5; because that allows the ratio spectrum planet/sun or planet/moon, to retain reasonable precision. No pre-

[*] The author has encountered this condition *once* at the McDonald Observatory, in Jan. 1947, when the depth of the 1.4μ band in α Orionis with resolution 80 was only 0.25. The temperature was −20°C. Dr. A. Adel has informed me that 0.2 mm has exceptionally been noted also at the Lowell Observatory. This should occur much more frequently at nearby Mt. Agassiz, 5,150 ft. higher.

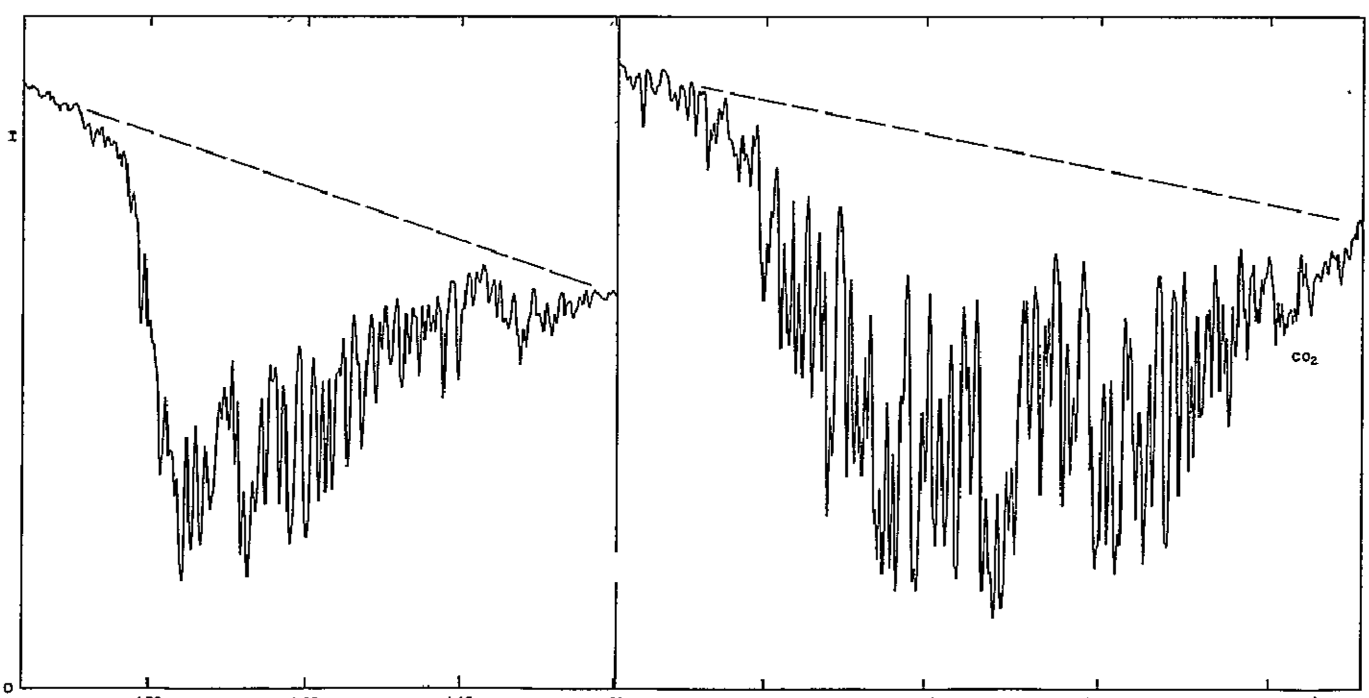


Fig. 9a Laboratory spectra of 1.4 and 1.9 μ bands of H_2O, total air path length 159 meters, 940 mb, 1.0 mm precip. H_2O (equivalent to 1.3 mm at 720 mb).

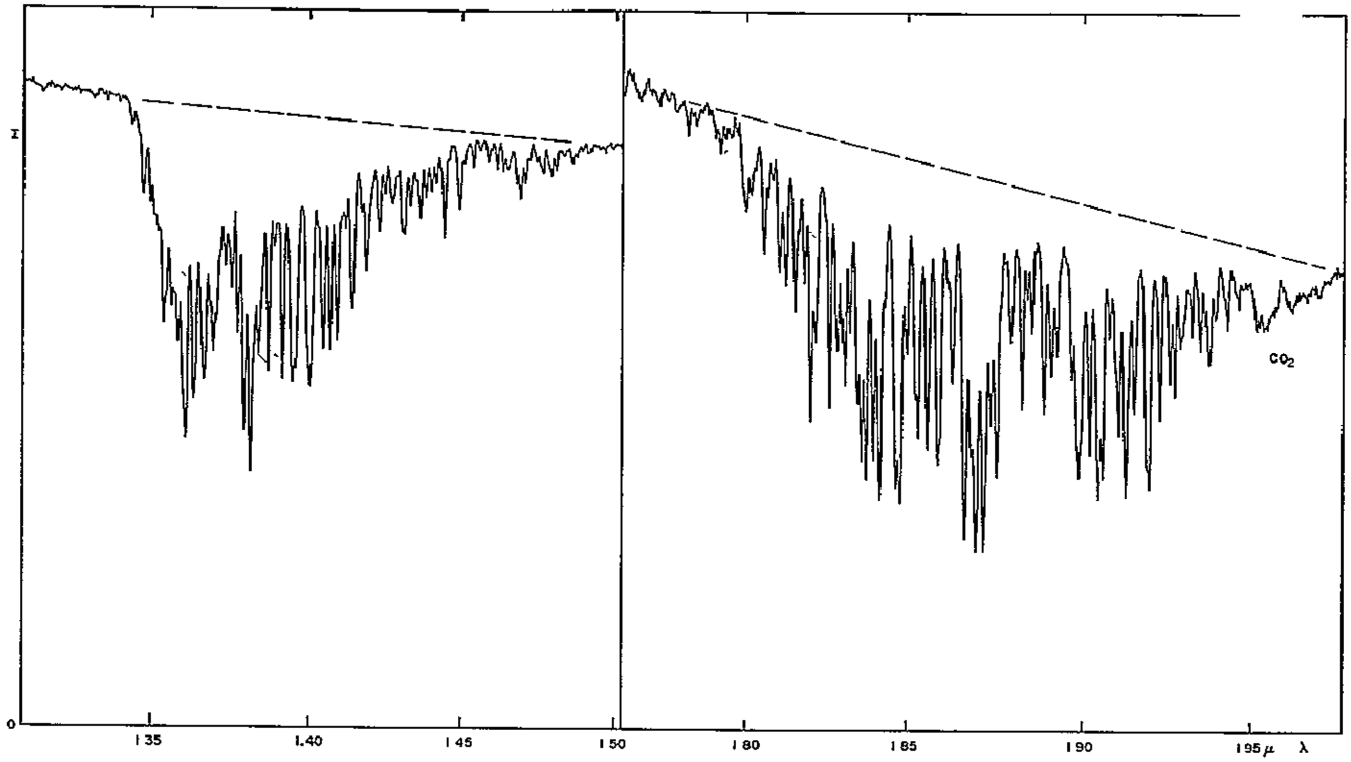


Fig. 9b Laboratory spectra of 1.4 and 1.9 μ bands of H_2O, total air path length 35 meters, 940 mb, 0.187 mm precip. H_2O (equivalent to 0.30 mm at 592 mb).

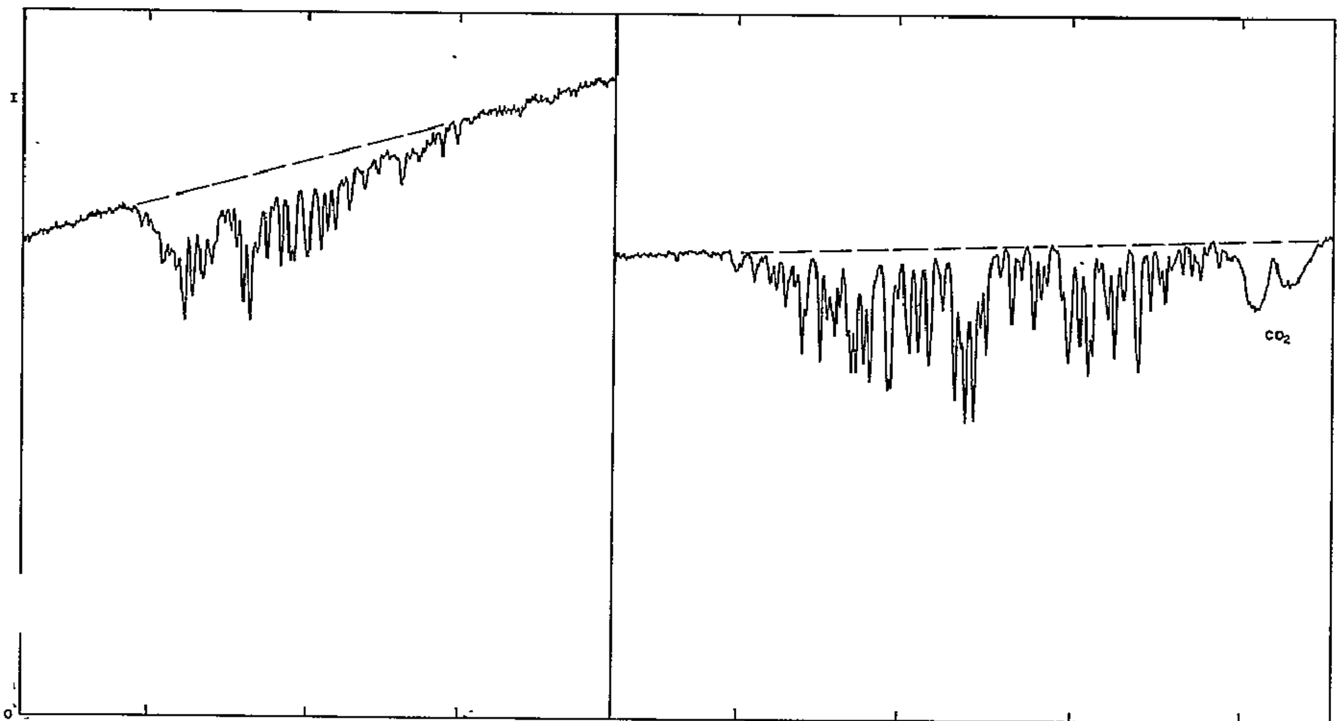


Fig. 9c Laboratory spectra of 1.4 and 1.9 μ bands of H_2O, total air path length 7.6 meters, 940 mb, 0.045 mm precip. H_2O (equivalent to 0.09 mm at 460 mb).

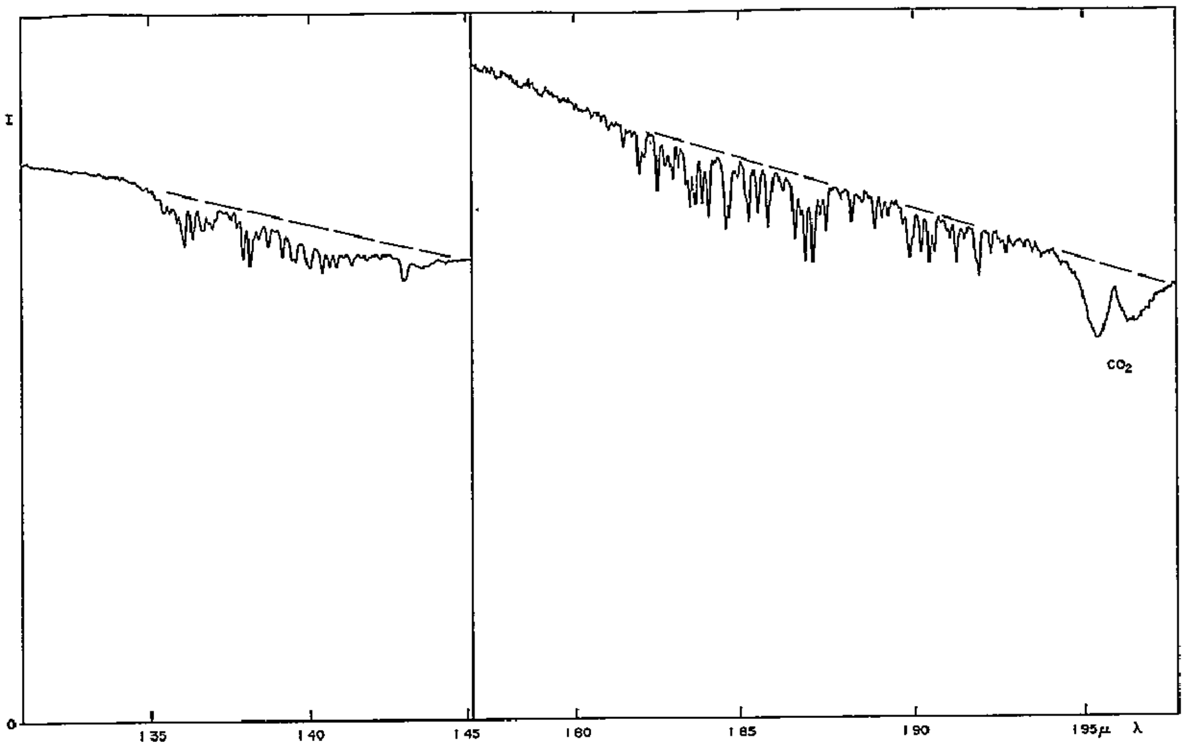


Fig. 9d Laboratory spectra of 1.4 and 1.9 μ bands of H_2O, total air path length 2.4 meters, 940 mb, 0.014 mm precip. H_2O.

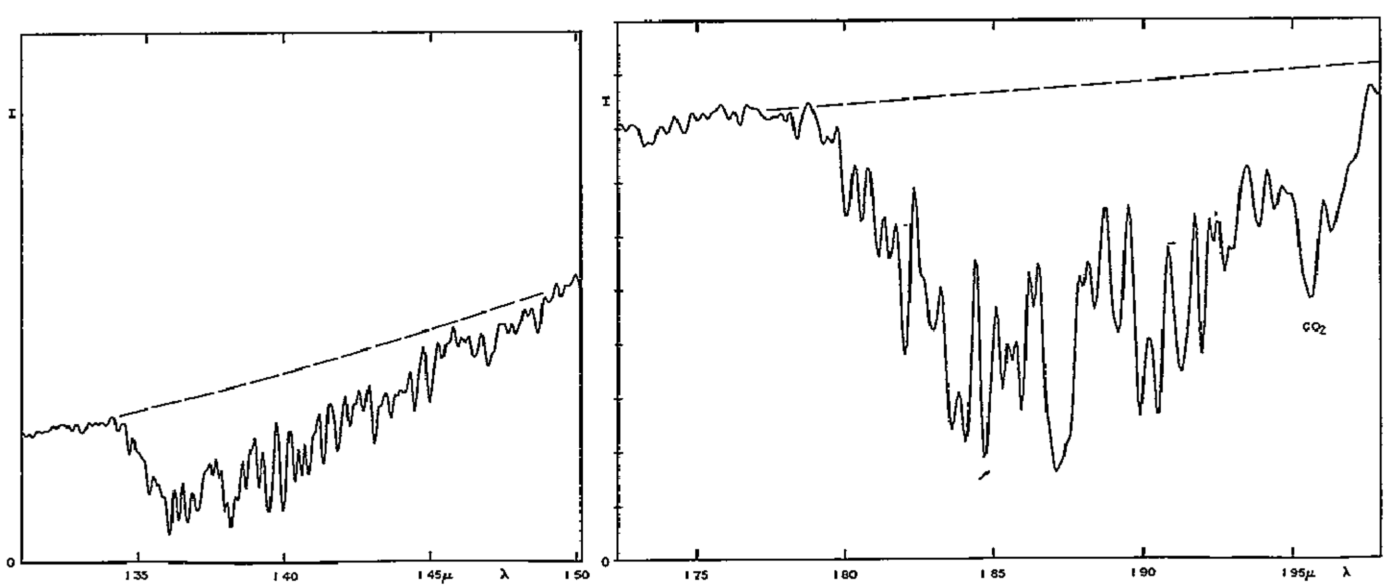


Fig. 9e The 1.4 and 1.9 μ H_2O bands of a lunar comparison spectrum, 61″ telescope, el. 8250 ft, 20 Nov. 1969; mid position 0^h34^m E, + 6°44′ dec.; airmass 1.1, T = +2°C, rel. hum. 0.16.

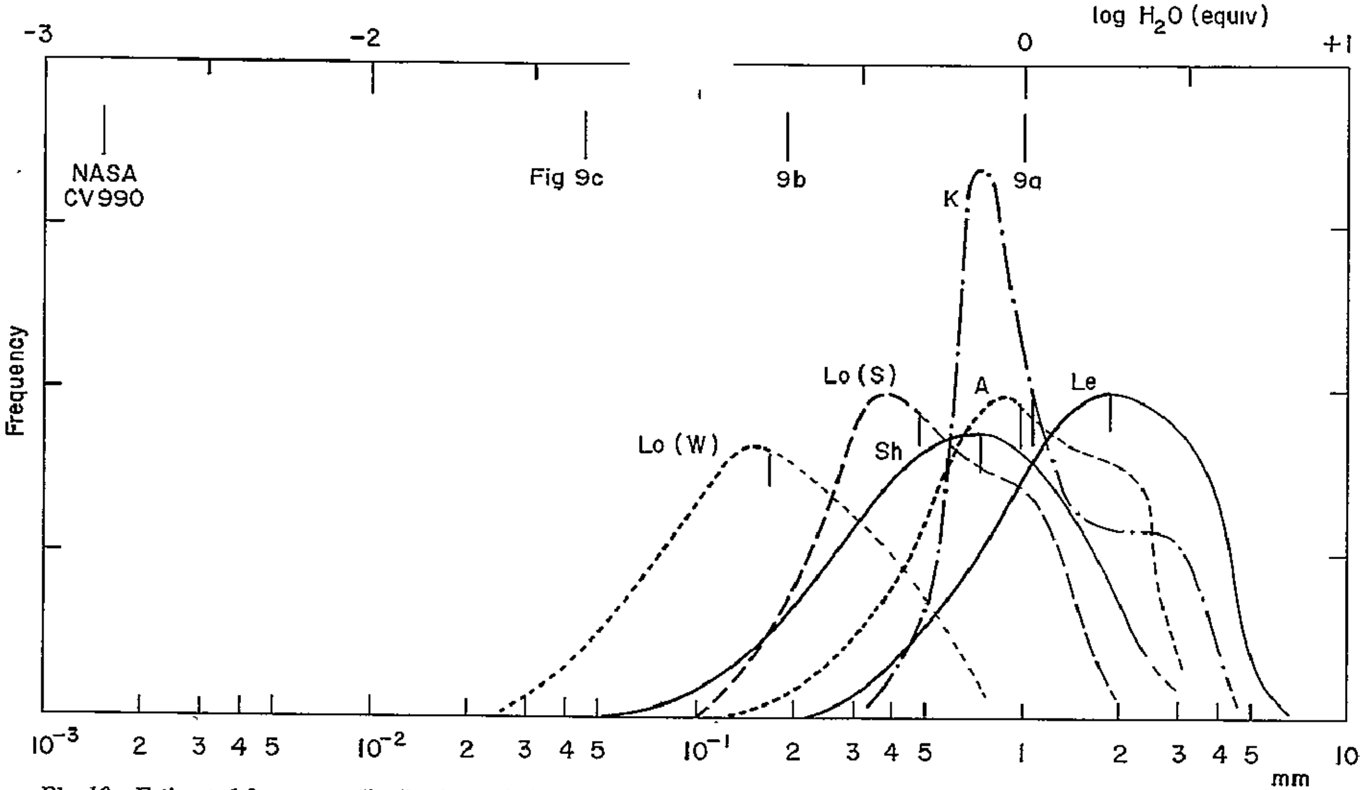


Fig. 10 Estimated frequency distributions of nighttime "equivalent" H_2O (reduced to $p = 940$ mb) for Mt. Lemmon (Le), Mt. Agassiz (A), Mt. Shasta (Sh), Mauna Kea (K), and Mt. Logan (cf. App. IV). Median values (50 percentiles) marked in each case.

cise answer will result, however, because it will depend on the resolution used in a given spectral region, and on the spectral region for a given resolution. Fig. 9 shows that telluric bands shortward of 2μ can be largely eliminated from a Type-1 IR observatory; but this will not be true for 2.5-2.8μ, 5.2-7.7μ, and $>14\mu$, though photometric measurements and partial spectroscopic results will become increasingly feasible at greater altitudes. Allowance for ambient atmospheric pressure and temperature in the absorption must be made for each band (and resolution) separately; it is therefore not made in Table I. Of great practical interest is further the *spread of conditions* at any one station, estimated in Fig. 10 on the basis of the 5, 25, 50, 75, and 95 percentiles in the Gringorten *Atlas*. For Mauna Kea and Mt. Shasta the conditions do not vary much between the January, April, and October graphs, and the average dew points were used for the five different percentiles listed. For Mt. Agassiz and Mt. Lemmon somewhat different curves are obtained for the three seasons; Fig. 10 gives the January data; the approximate systematic shifts for April and October may be read from the data in Table I. For Mt. Logan, Canadian Yukon, both the January and July distributions are given. Since one is, in practice, always interested, at any wavelength, in *reducing strong or moderately-strong H_2O absorptions,* which are roughly proportional to $\sqrt{pN}$, we have accordingly allowed in Fig. 10 for the lower pressures at high altitude. This, incidentally, makes possible direct comparisons with Figs. 9*a*-9*c*, as entered in Fig. 10 (9*d* is not entered, not being applicable, showing only weak lines). The differences in the spread of conditions for the various stations is noteworthy: Mauna Kea, in the tropics, often favored by a barometric high (subsidence of upper atmospheric air), stands out by its uniformly good conditions over half the time, with a bimodal spread indicating a separate class of more stormy conditions. The continental stations are favored by a tail of exceptionally dry conditions, the extent of which is still somewhat uncertain.

Obtaining higher precision for the frequency curves in Fig. 10 by direct observations at night, will be *a prime objective of future surveys.* From Fig. 10 some interesting conclusions, of a tentative nature, may be drawn: While the water vapor over Mt. Agassiz is at any one time on the average about half of that on Mt. Lemmon, in accordance with expectations based on the elevation and latitude differences, and confirmed by direct measures made by the author from aircraft, it is yet possible to duplicate most of what can be done on Mt. Agassiz on Mt. Lemmon, given *time*. (This is not to say that time is always available.) Suppose one wishes to produce an atlas of stellar spectra, with H_2O equivalent less than 1.0 mm. Then 12-15% of the nights on Mt. Lemmon can be used; some 42% of the nights on Mt. Agassiz, some 47% on Mauna Kea, over 60% of the nights on Shasta, and all clear nights on Mt. Logan or Mt. McKinley. On the other hand, if one wishes to work *only* at less than 0.3 mm equivalent H_2O, Mt. Lemmon and probably Mauna Kea would be unsuited, Mt. Agassiz would yield about 3-4% of the nights, Shasta 16-18%, and Mt. Logan in July 30%, in winter (if accessible) all clear nights. It should not be overlooked, however, that the favorable comparison for Mt. Logan or Mt. McKinley is paid for by the extreme altitude which reduces the "equivalent H_2O content." The more moderate altitude, the greater accessibility, and the more southern latitude of Mt. Shasta, would appear strong arguments for its ultimate year-around use. Additional comparative data and commentary are found in App. IV

4. *Comments on Some Mountain Sites*

The following U.S. sites are accessible (cf. Table I): Mt. Lemmon, near Tucson, Arizona; Mt. Agassiz, near Flagstaff, Arizona (which has a chair lift operating all year, to be replaced by a cable car in the near future); White Mountain, California, Barcroft Laboratory (helicopter); Pikes Peak, Colorado (summertime only); and Mauna Kea, Hawaii.

Mt. Lemmon is becoming available as a site for IR astronomy later in 1970*. A map, photographic coverage, and descriptions are found in Appendix I. It is favored by a good record of clear skies, a dry climate, unusual accessibility, and low wind velocities. Because of Tucson, there is no need for a new base at lower altitude.

Mt. Agassiz was studied during four visits in 1963 and some later; and from time to time from light aircraft. The U.S. Forest Service has designated the area as "recreational." An extensive development program is now under review that could benefit future scientific operations. In 1963 the author made an informal proposal to NASA for a partly-underground 60-inch telescope installation on Mt. Agassiz of the Newtonian type. An improved version (more compact) of the Cassegrain type is reproduced in Appendix II. No new base is needed because of the proximity and altitude (7,000 ft) of Flagstaff, with adequate facilities.

The staff of the Space Sciences Laboratory of the University of California (Berkeley) has made systematic studies of White Mountain, California; not at the 14,200 ft summit, which is rather inaccessible, but at the existing Barcroft Laboratory, at 12,500 ft. A report has been issued (O'Connor, Welsh, and Tayeb 1969) describing observations extending over 18 months, of percentage cloud-cover, surface measures of water vapor, and radio-sonde (balloon) atmospheric water-vapor profiles. The authors note a concentration of water vapor in the lowest few-hundred meters above their Laboratory (possibly due to daytime evaporation of snow); and some remaining uncertainties in the absolute H_2O vapor calibrations (that have troubled other ground-based measures as well). The site is remote as is apparent from maps; and occasional very high winds occur (a dome housing a Cal. Tech. test telescope was damaged by winds in excess of 120 mph).

Pikes Peak, Colorado, is interesting because of its detachment, 60 miles to the E, from the main chain of the Rocky Mountains; and accessible from Colorado Springs, which has a branch of the University of Colorado. It is approached either by a toll road, operated by the City of Colorado Springs; or by a cog railway opened in 1891, privately owned (runs daytime, May-October only). The writer has inspected the summit area as the guest of the City Manager of Colorado Springs, twice by car. Two maps and some photographs are reproduced in Appendix III. The site is capable of development for scientific programs; R. Millikan conducted cosmic ray experiments in 1923, and many other scientific expeditions have taken place during the past century. A considerable body of meteorological information has been collected over 22 years of near-continuous observation during three periods between 1874 and 1966; cf. Appendix III. The railroad, which ascends 7,540 ft, cannot be operated in wintertime because of snow and ice on the track. The road is cleared May 1–Oct. 15, but could be plowed at a modest charge during the winter if required.

Mauna Kea is well above the inversion layer and the fair-weather ocean cloud cover; cirrus (visible some 25% of the time), stemming from the high-altitude return-flow from the tropical convergence, and occasional storms, set limits to IR observations on an otherwise excellent site. Considerable data exist on Mauna Kea, starting with our test results of 1964; the latter will be described in a separate *Com-*

*A Users Group of interested universities was organized Feb. 2, 1970, on an interim basis *munication*. An attractive and suitable base exists at Hale Pohaku (9,200 ft) which can be further developed; it is normally within easy reach (20 min. by jeep) of the summit.

Tenerife in the Canary Islands is being developed by an English IR research team (not at the summit, listed in Table I, which is volcanic).

Mt. Rainier and Mt. Shasta have in Table I comparable amounts of water vapor. Both are dormant volcanoes. Mt. Rainier's rim is free of snow in summer (Fig. 33a) because of its intrinsic heat; temperatures as high as 79°C have been measured. Moxham *et al.* (1965) recorded temperatures up to 33°C with a radiometer (3° beam width) overflown at 16,000 ft, in spite of the resulting averaging with the snows. The precipitation on the slopes of Mt. Rainier at the middle altitudes (5,000-10,000 ft) is enormous; at the base near Paradise (5,500 ft) the annual precipitation averages 100 inches, with annual snowfalls recorded up to 80 ft (30 ft packed). Mt. Rainier has 41 glaciers (map in App. IV). The cloud cover in the area is high, 0.8 according to Fig. 8. Without major development, Mt. Rainier could not be used for IR astronomy; a base at an intermediate level would itself pose serious problems of access (cf. App. IV).

Mt. Shasta is a National Forest, unlike Mt. Rainier which is a National Park. The glaciers are small in total area, a few percent of Mt. Rainier (map in App. IV); while the precipitation and snowfalls are much less. The fractional cloud cover in the area, according to Fig. 8, is around 0.46. The more Southern latitude (by 5°.4) would benefit planetary observations, as well as increase percentage sky coverage. The average precipitation at the town of Mt. Shasta (3,540 ft) is 37 inches; the average snowfall, 115 inches; the mean daytime sky cover, 48%; the annual mean number of clear days, 163, and of partly cloudy days, 85. Thunderstorms occur on the average of 13 days per year, heavy fog on 7 days. Volcanic hazards appear minor or absent; a few hot springs occur near the summit (Williams, 1932). The southern slopes are nearly bare in summer (App. IV). The mountain is promising for IR developments. A good base exists at 7,500 ft (App. IV), from which a cable car to the summit could be constructed at a very modest cost.

Table I shows that Shasta and Pikes Peak are nearly equal in mid-winter, but that Shasta is better the rest of the year. The fractional cloud cover of the two areas are about 0.51 and 0.46, favoring Shasta (Fig. 8). The average cloud cover observed at the *summit* of Pikes Peak is 0.40; the Shasta figure appears unknown. Comments on Mt. Logan (Canadian Yukon, 60°32'N, 140°27'W, 19,850 ft = 6,055 m) are found in App. IV, a site possibly suitable for special programs.

Acknowledgments. I am indebted to A. Thomson and C. Benner for assistance in the computations of Table I; to Dr. D. P. Cruikshank and Mr. Thomson for the laboratory spectra of Fig. 9; to Mr. F. de Wiess and Mr. C. L. Edwards for the design of Fig. 21; to Mrs. F. Larson for a literature search of relevant maps and published data; and to Mr. S. Larson for assistance in the composition of the figures. Prof. Drummond Rennie contributed important comments on this paper, quoted in App. IV.

APPENDIX I
*Mt. Lemmon**

Mt. Lemmon is the most accessible of the sites in Table I over 9,000 ft. Working there involves no appreciable strain though the altitude is felt.

The Base is reached by an excellent county road that terminates at the ski lift area, 1.8 miles from the Base entrance. The final 1.8-mile approach-road (and 800 ft rise) is in good condition. Snow clearance by Pima County is up to the ski lift; the Base is responsible for its own snow clearance and that of the 2-mile approach. The Base is supplied with commercial power and telephone, has its own water system (1 million gallon storage, in two tanks), and large storage facilities for diesel fuel. There is a helicopter pad just outside the gatehouse. Reference is made to Figs. 11a-b for maps of the Mt. Lemmon Base, and Figs. 12-16 for aerial views taken on March 7, 1970. A detailed map is available.

The solar 4-meter spectrometer, used in the NASA CV 990 in 1968 for the Arizona-NASA Atlas of the IR Solar Spectrum (*LPL Comm.* Nos. 123-5, 160, 161, 163-5, 1969), was installed on Mt. Lemmon in March 1969 and used to obtain back-up spectra for the CV 990 Atlas (in part for purposes of wavelength scale and identification; in part for extension beyond 3.1μ). This installation is shown in Fig. 17.

The sky on Mt. Lemmon, when clear, is usually deep blue, the top of the haze layer in S. Arizona being normally not over 7,000 ft. Condensation trails are no serious problem; when they are seen they are usually short and vanish promptly. The wind veloci-

* Named for Dr. J. G. Lemmon (Lemmon Herbarium, Oakland, Cal.) who ascended the Mt., June 1882.

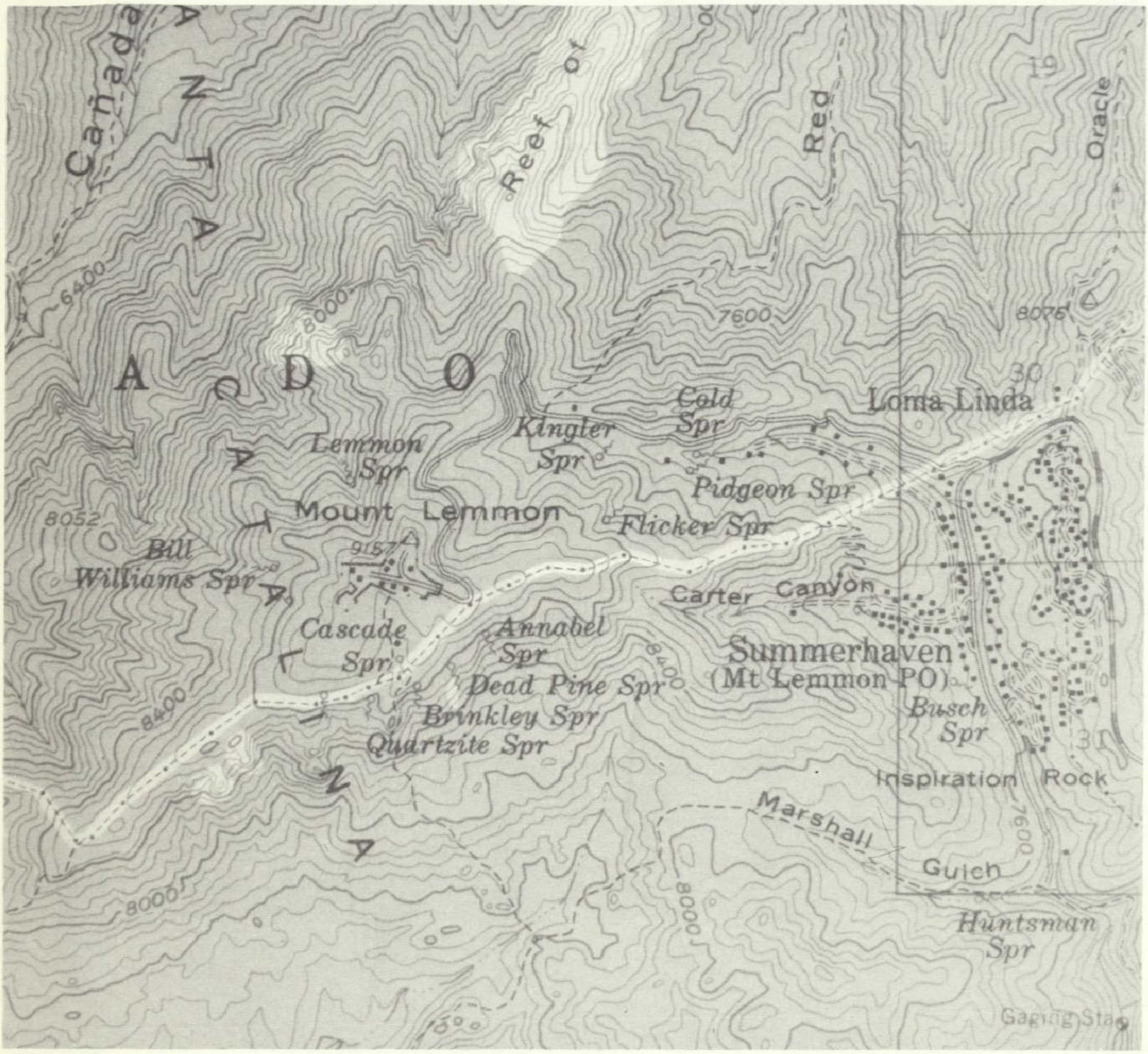


Fig. 11a Section of topographic map of Mt. Lemmon summit area. Some buildings at nearby Summerhaven are summer cottages (part-time occupancy). Contour interval 80 ft.

ties are usually low to moderate. During the monsoon (end June to mid-September), observing conditions are poor. The rest of the year is satisfactory. The proximity of Tucson with its extensive astronomical facilities (40 miles by excellent road) is an asset and a great convenience.

With the aid of pilot balloons the writer has investigated the airflow pattern over the Mt. Lemmon summit on a typical clear Spring evening (after sunset), with a West wind of about 10 mph. The flow pattern was considered satisfactorily regular, with no major turbulence apparent. On the basis of experience with other summits the astronomical image quality is expected to be good to excellent. Direct image tests have begun.

Daytime water vapor measurements on Mt. Lem-

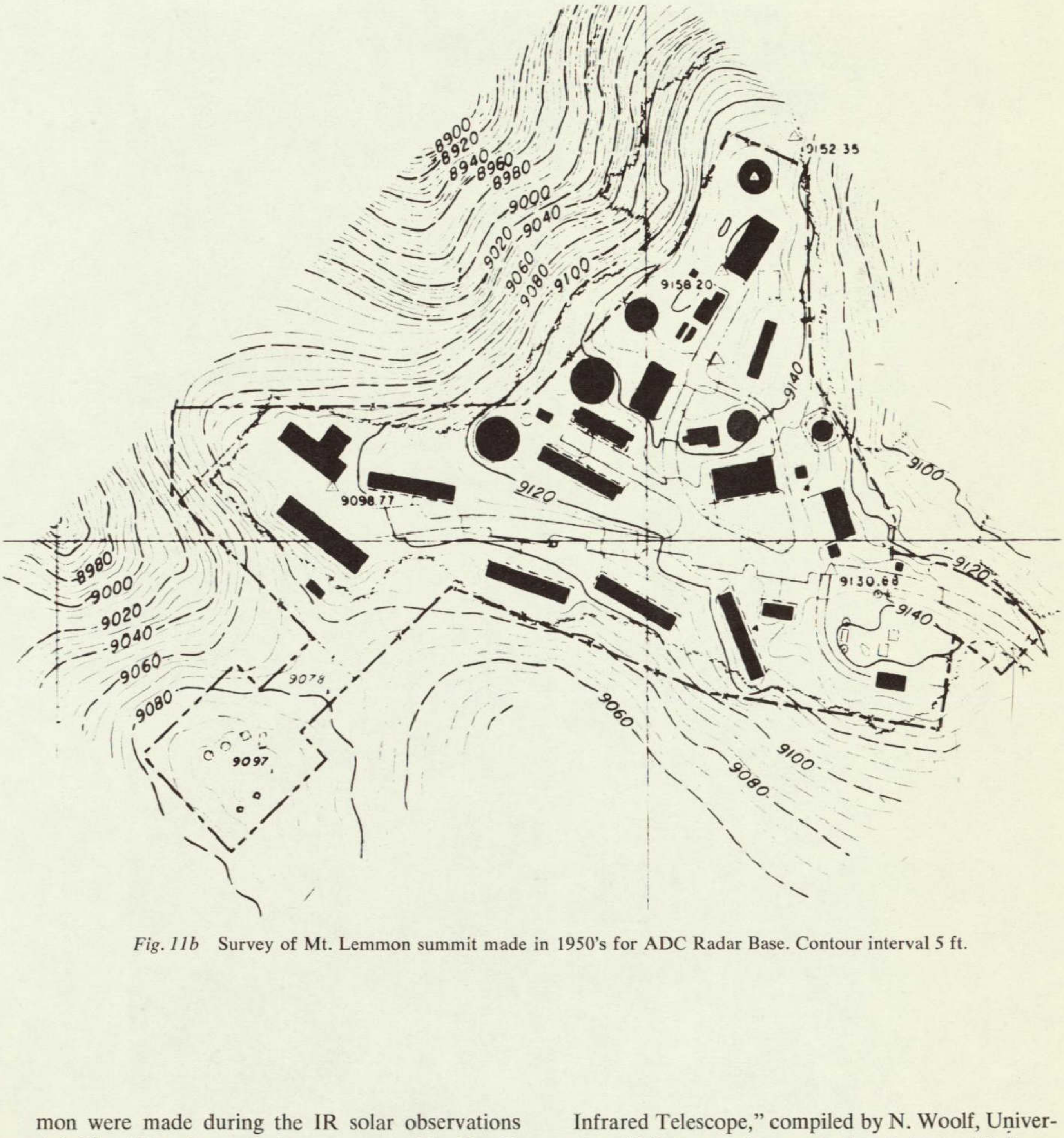


Fig. 11b Survey of Mt. Lemmon summit made in 1950's for ADC Radar Base. Contour interval 5 ft.

mon were made during the IR solar observations (cf. Fig. 17) using a device constructed by Dr. F. Low and Mr. A. Davidson. These and similar measures made on other mountains are collected in a forthcoming *Comm.,* together with a new calibration of the Low device (which basically confirms Dr. Low's original calibration).

Reference is made to an unpublished study "Site Selection Study, Final Report, for University of Minnesota-University of California (San Diego) 60-inch Infrared Telescope," compiled by N. Woolf, University of Minnesota, for comparison between Mt. Lemmon and other U.S. high-altitude sites. This report was received after the present manuscript was completed. Its conclusions are based on a survey conducted by Dr. Woolf and his staff, entirely independently of the study described here. It pays special attention to medical and logistical considerations. It endorses the use of Mt. Lemmon for future IR operations by university-type organizations.

Fig. 12 Mt. Lemmon Base and Catalina Highway, seen from ESE, with Picacho Peak (3,382 ft) left, in low-level haze, 40 miles beyond Mt. Lemmon.

Fig. 13 Close-up of Mt. Lemmon Base, from WNW. Two radar domes deflated. Cf. Fig. 11.

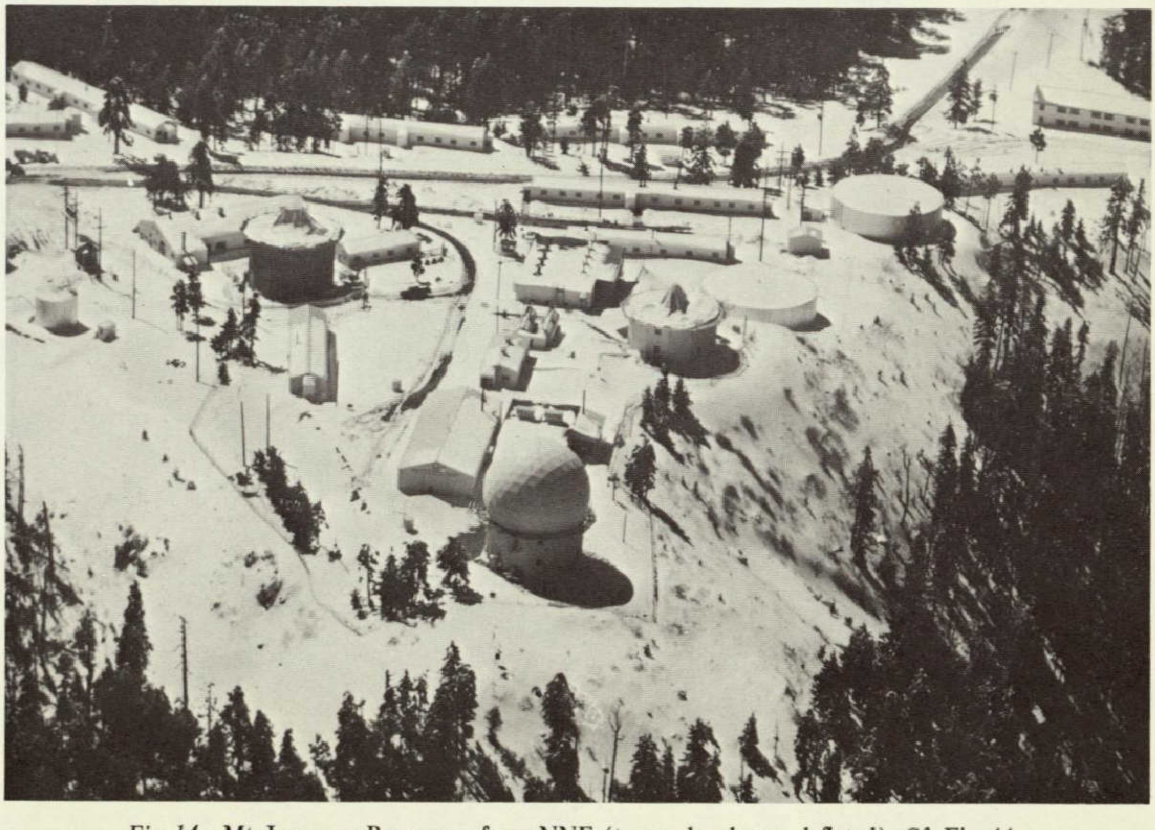


Fig. 14 Mt. Lemmon Base, seen from NNE (two radar domes deflated). Cf. Fig. 11.

Fig. 15 West Section of Mt. Lemmon Base, seen from N. Cf. Fig. 11.

Fig. 16 Mt. Lemmon Base, from S. Cf. Fig. 11.

Fig. 17 Solar 4-meter spectrometer mounted on Mt. Lemmon, April 1969.

APPENDIX II

Mt. Agassiz, Arizona

Mt. Agassiz can be reached most of the way through a chair lift from the Snow Bowl (9,530 ft), 15 miles by good road from Flagstaff. The topographic map of the summit area, showing the ski lift, is reproduced in Fig. 18; Fig. 19 gives a general view.

The Lowell Observatory, itself located at 7,200 ft, had from 1926–34 a Station on the San Francisco Peaks, E of Mt. Fremont (Fig. 18) at about 11,500 ft; but found that on the coldest and driest nights at the main observatory the conditions for Martian spectroscopy were at least as good as at the Station *when it could be reached*. This problem has already been touched on (pp. 135–136): if a site cannot be reached during the optimum conditions (often after a heavy snowfall) it loses much of its significance. (The Station had a 12-inch and a 15-inch reflector, used together, with a roll-off roof building. Living quarters were a dugout, now caved in).

The present Peaks are about 3,000 ft lower than the original volcano whose main crater area eroded during the Pleistocene (Robinson, 1913). Major effects of glaciation are evident and some slopes are rock slides.

The Mt. Agassiz chair lift terminates at 11,608 ft (3,540 m), 750 ft (230 m) short of the summit (cf. Figs. 18 and 20). The LPL staff made several ascents soon after its completion (fall 1962). The LPL observer, Mr. A. Herring, spent part of the night of Feb. 13, 1963 at the terminus, using his 6-inch

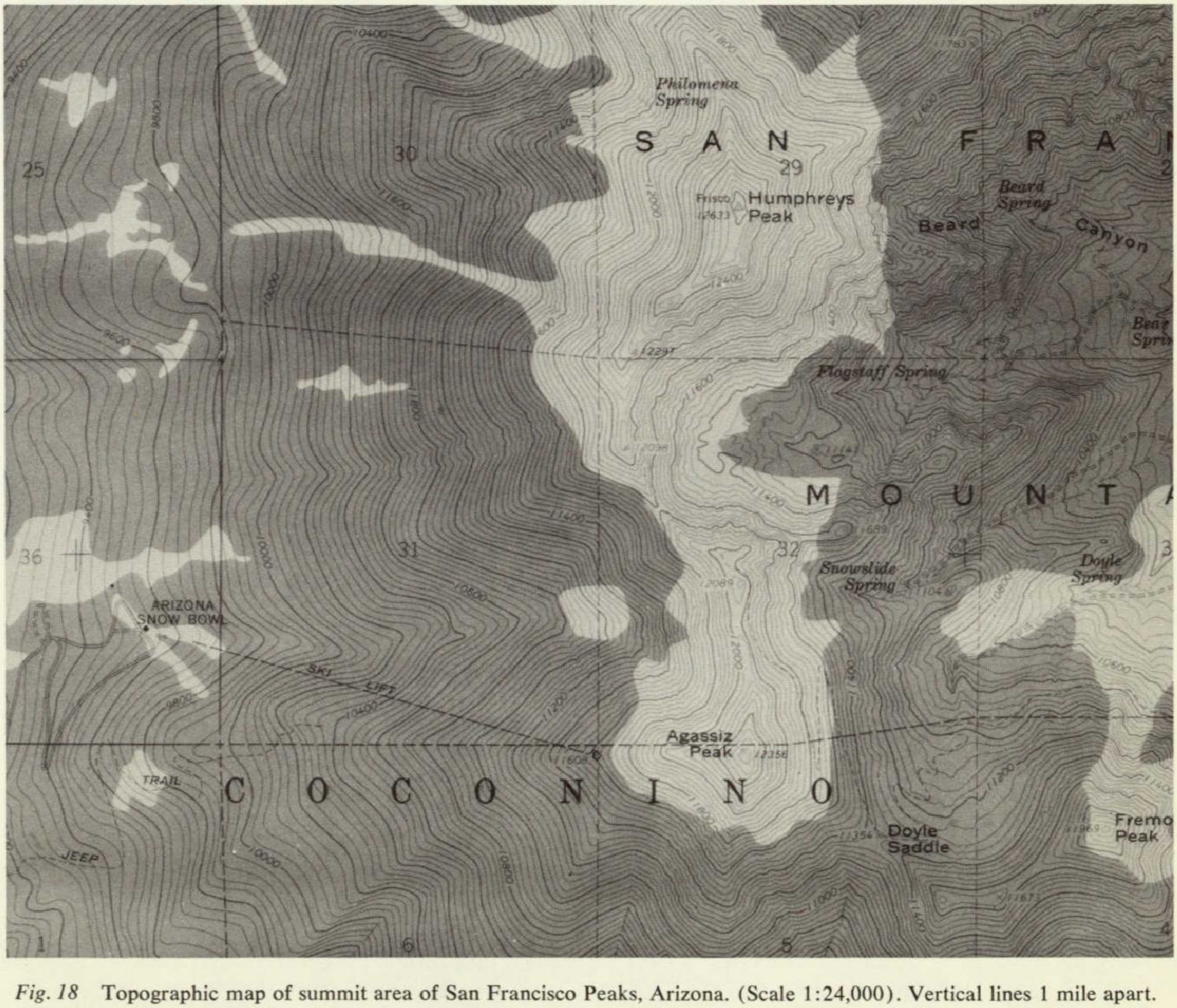


Fig. 18 Topographic map of summit area of San Francisco Peaks, Arizona. (Scale 1:24,000). Vertical lines 1 mile apart.

Fig. 19 View of San Francisco Peaks from SW, Mt. Humphreys left, Mt. Agassiz center (cf. Fig. 18). Early Fall.

Fig. 20 Mt. Agassiz, seen from W. Linear marking across center is track of chair lift which terminates just below summit.

reflector, by special arrangement with the owner of the ski lift. He rated the seeing 6-7 (very good), but a N wind with gusts at 30-40 mph. caused the telescope to be unsteady. The temperature was 18°F = −8°C, the transparency good but not exceptional. Other visits were made by LPL engineers in 1962–63, who discussed load limits on the chair lift (1,500 lbs, when seats are removed) and with the bulldozer (4,500 lbs). The writer inspected Mt. Agassiz on Nov. 18, 1963, as guest of the owner of the ski lift, Mr. Bainbridge, who arranged for a special run and accompanied me to the summit; and who clarified much on possible observatory operations.

Inquiries into the water-vapor content above Mt.

Agassiz were also made. I am indebted to Mr. C. H. Reitan of the Institute of Atmospheric Studies, author of a study of the distribution of water vapor over the U.S.A. (Reitan, 1960), for an analysis of this question, based on radio-sonde data obtained at Phoenix, Arizona, and Las Vegas, Nevada, whose average should be representative for Northern Arizona. In his memo of 20 February, 1963, Mr. Reitan wrote as follows (condensed):

"An estimate of the upper-level dryness may be made from the frequency of 'motor boating,' which means that the moisture content is less than the threshold of detection of the humidity element in a radio sonde. It is a function of the temperature:

T	+10°	0°	−10°	−20°	−30°	−40°C
Rel. Hum.	18%	20%	24%	25%	30%	34%

From the observed frequency of 'motor boating' at the 650 mb level (Mt. Agassiz), one can compute the percentiles of these tabular humidities, using the mean monthly temperatures with altitude from U.S. Weather Bureau Tech. Paper 32 (a ten-year summary)." The result is given in Table II, in which *W* is the amount of measured water vapor in the column between 675 and 325 mb (95% of the total above 675 mb and about 1.2x the amount above 636 mb, which is wanted). It is noted that the *W* values in Table II are not unlike the 50% values for Mt. Agassiz of Table I. It may be added that the annual average H_2O scale heights, computed from the monthly averages at 650 mb and at 350 mb compiled by Mr. Reitan, are 2.27 km for Phoenix and 2.18 km for Las Vegas, somewhat larger than the 1.6 km tropospheric average adopted in Table I.

TABLE II

Frequency of motorboating at 650 mb level in N. Arizona (C. H. Reitan)

Month	Phoenix % motorb.	Max. W. (mm)	Las Vegas % motorb.	Max. W. (mm)
Jan	40%	1.7	38%	1.5
Feb	51	1.6	39	1.5
Mar	50	1.7	40	1.5
April	39	2.1	24	1.9
May	35	2.5	16	2.2
June	38	3.4	36	3.0
July	6	3.8	12	3.7
Aug	7	3.7	21	3.5
Sept	23	3.5	26	3.3
Oct	43	2.8	44	2.6
Nov	51	2.3	44	2.1
Dec	54	1.9	51	1.7

The author proposed to NASA with his memorandum of 27 July 1963 that a duplicate of the inexpensive 28-inch telescope (later described in *LPL Comm.* 111, 7, 47–51) be placed on Mt. Agassiz as a first step toward the creation of a *high-altitude station* in the U.S. Later that year a modified proposal was made that appeared to meet objections to prominence on a mountain designated for recreational purposes. However, because of more immediate pressures at this Laboratory (*Ranger, Surveyor,* Mars spectroscopy), no prompt execution was foreseen. *With the advent of Fourier Transform Spectroscopy, the needs for a high-altitude IR observatory have enormously multiplied.* The design shown in Fig. 21, *a, b,* is a Cassegrain version of the concept proposed in 1963 in Newtonian form. The Cassegrain version is more compact, and avoids light losses due to cross polarizations. The spectrometer room can, of course, be enlarged and a small shop added. Fourier Transform Spectroscopy has been using large Coudé installations (sometimes with severe light losses due to multiple reflections). In Fig. 21 the stationary focus requires only three reflections, two of normal incidence. The flat can be of selected plate glass.

At the Snow Bowl the accumulated winter snowfalls reach about 6 ft. Mt. Agassiz's summit has usually around 1 ft because the snows blow off. The snows fall between early October and late April. The percentage clear weather, outside the 3 months' summer monsoon, is reportedly high, both at the Snow Bowl and the summit (around 80%). At the summit winds are typically around 20 mph and are not known to have exceeded 85 mph. Southward 30° slopes (cf. Fig. 21) are available both at the terminus of the present chair lift and at the summit. Especially after the present chair lift has been replaced, and the summit is directly accessible by closed cable cars year around, the site will take on a special interest for IR astronomy.

In Table I the H_2O content over Mt. Agassiz is geometrically intermediate between Mt. Lemmon and Mt. Shasta. The ratios in the *efforts* required of establishing IR observing stations cannot yet be fully assessed. For the immediate future, both Mt. Lemmon and Mt. Agassiz can clearly contribute, each in their own major way.

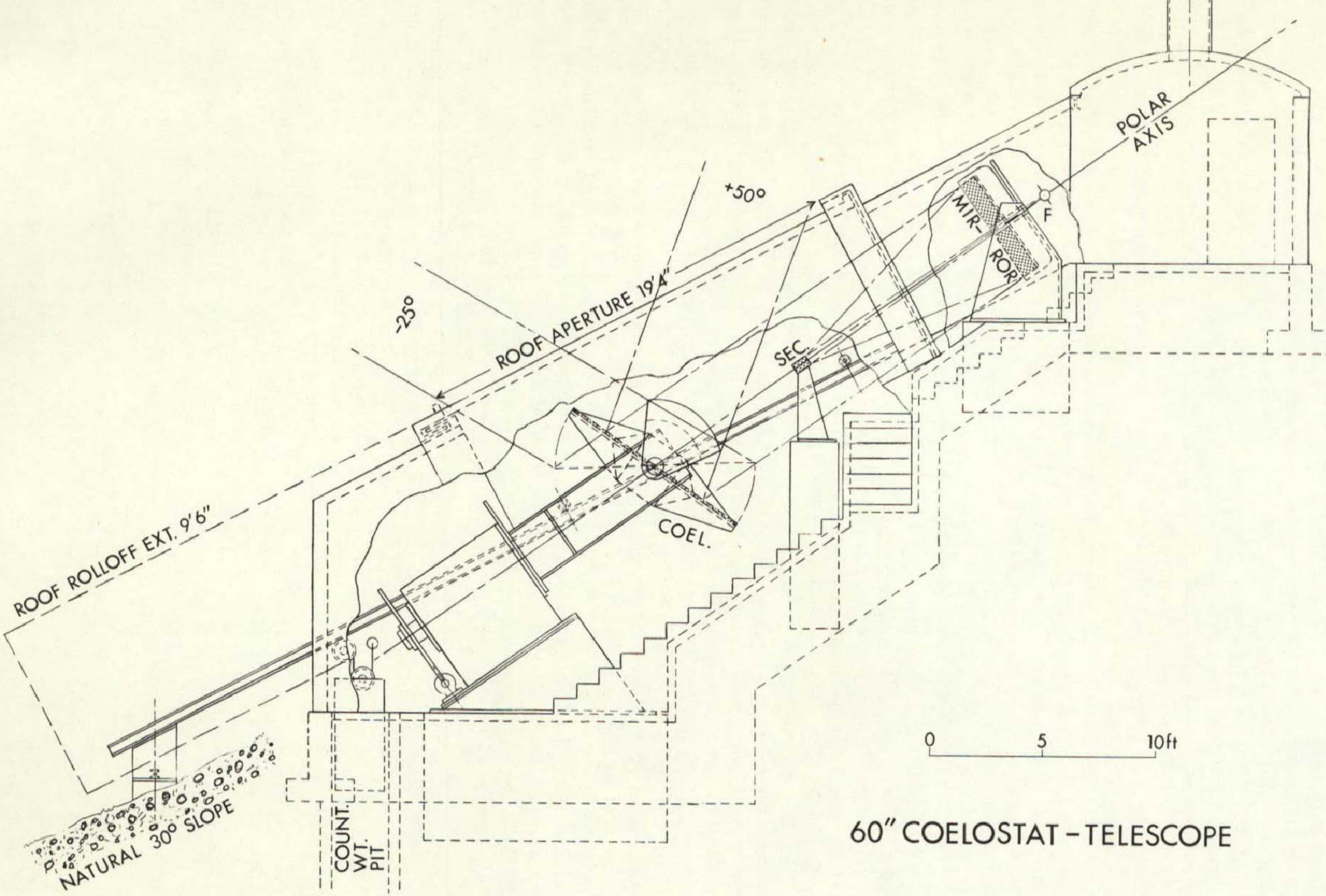
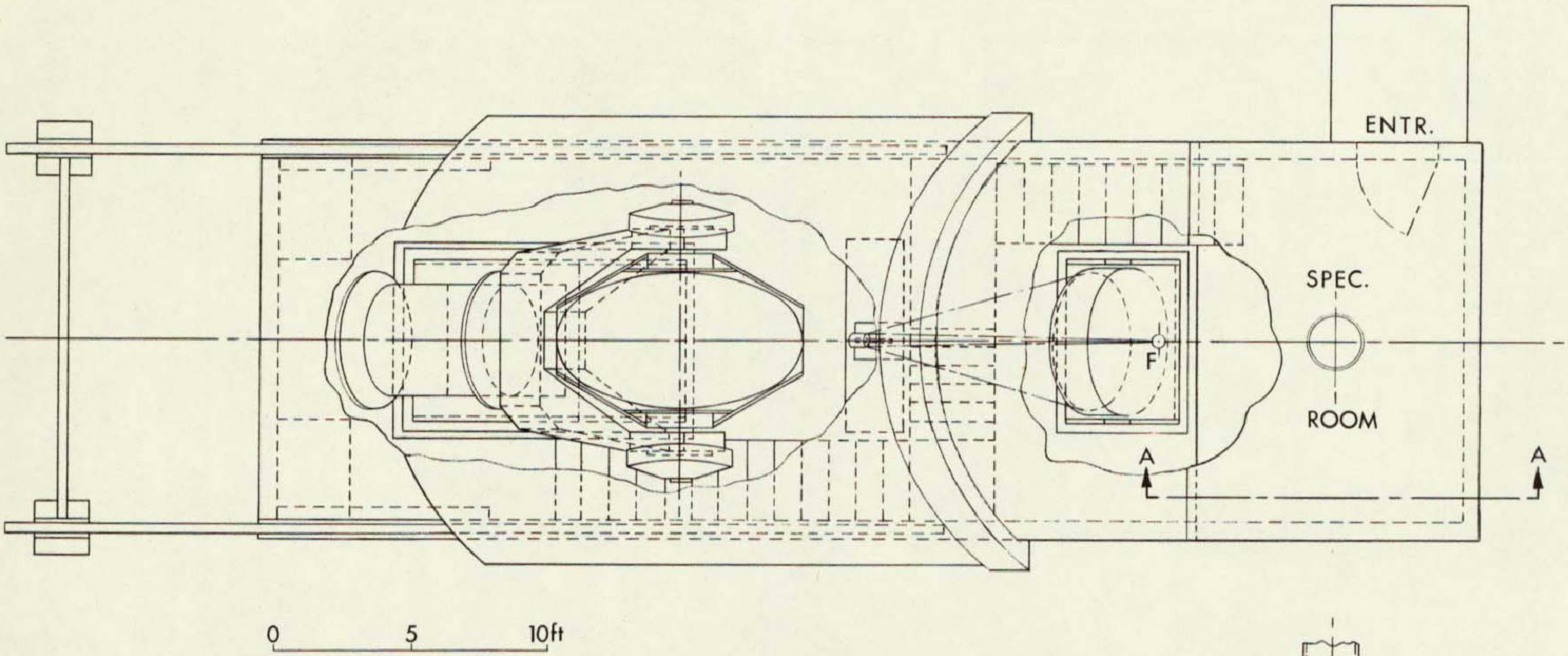


Fig. 21a Design of low-profile 60-inch telescope installation with spectrometer room (elevation). No component weighs in excess of 3000 lbs (F. A. de Wiess).



60″ COELOSTAT-TELESCOPE

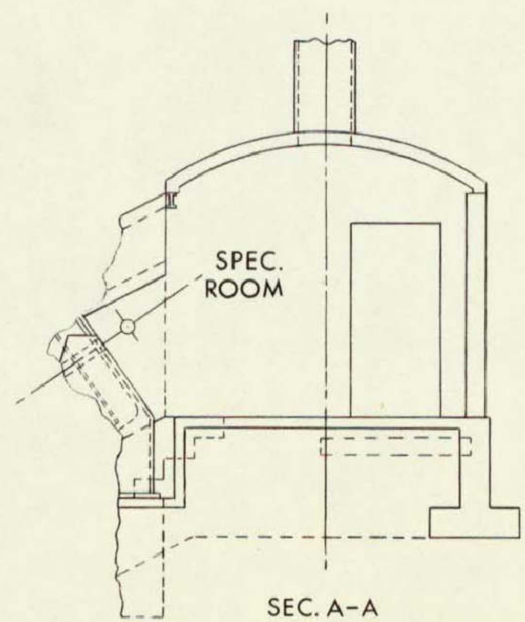


Fig. 21b Same as 21a, in plan view.

APPENDIX III
Pikes Peak

The mountain seen from the north is shown in Fig. 22. The topographic maps of the summit area are found in Fig. 23*a* and *b*. In summertime the temperature is comfortable and the summit is reached (by over 350,000 visitors) either by Route 250 or a cog railroad installed in 1890 (Fig. 24); but this is a time of high humidities. The railroad can, of course, not be used 6-8 months of the year with snow and ice on the tracks. In mid-winter the daytime temperature is around −16°C, with night temperatures recorded down to −39°C. The summit snowfall is not as heavy as in the central Rockies and most of it blows away to lower levels because it is dry. Rarely more than 1 ft remains on the summit. Glen Cove (Fig. 25), cannot normally be reached from the summit during the observing season (Oct.-May). Other parts of the road are shown in Fig. 26. Above the gate at 7,700 ft (Fig. 27) the road is closed Oct. 15-May 1 but could be cleared by the City of Colorado Springs by arrangement. Observing on Pikes Peak will mean in practice having local overnight accommodations. Summertime experience at the restaurant (Fig. 24; staff ~ 35) has shown that all but 10 percent of young adults are able to be there for some weeks; it takes about three days to acclimatize.

Helicopter transportation to the summit has been used. Commercial electric power (now reaching Glen Cove) will be installed in buried cables by late 1970. The Fitzsimons General Hospital of Denver has an active High Altitude Lab. at the summit (Fig. 28).

The meteorological data for Pikes Peak are unusually complete. The Signal Corps carried out meteorological observations from January 1874 through June 1888, published in *Harvard College Observatory Annals,* **XXII** (1889). I am indebted to Dr. J. W. Berry, ESSA-WB State Climatologist, Denver, Colorado, for a summary of data with his letter of February 5, 1969, transmitted by Dr. P. M. Kuhn of ESSA, Boulder, Colorado. The temperature results, listed by month, are found in Table III. Line 6 of the Table gives the total precipitation in inches averaged over the same 15 years, taken directly from the *Harvard Annals* volume referred to. Lines 7 and 8 of Table III give the average hourly wind movement on the summit for each month, around midnight ($0\text{-}1^h$ A.M.) and noon ($12\text{-}13^h$).

Reference to the original *Harvard Annals* publication on Pikes Peak is of extraordinary interest. The "Extract from Daily Journal," on pages 459–475, is a very remarkable piece of scientific literature, containing many items that must be pondered by anyone intent on establishing an IR observatory on a high mountain. Three summarizing sections of the Introduction (*op. cit.* p. xi) are quoted:

> "Severe and prolonged wind-storms are unusual on Pikes Peak, and the days are comparatively infrequent when the mean hourly velocity equals or exceeds fifty miles per hour. The most remarkable wind-storms were those of September 28-29, 1878, when the mean velocity for twenty-four hours was 71 miles, and December 25, 1883, when the mean velocity was 70 miles per hour. The highest extreme velocity recorded at Pikes Peak was comparatively low, being 112 miles, May 11, 1881.
>
> "The mean annual cloudiness on Pikes Peak is 40 per centum, ranging from 33 per centum in November to 74 per centum in July. The tendency is to an excess of cloudiness during the late spring and the late summer, with the least amounts from September to January, inclusive.
>
> "Pikes Peak is celebrated for its electrical storms. Many interesting details of these are given in the observer's journals. The storms only occur when the air is moist; the most favorable condition is during the time a light, soft snow is falling. When the hands are held up sparks emanate from the tips of the fingers. At such times with considerable wind the anemometer cups look like a circle of fire. Each flake of snow as it alights on a mule's or burro's back gives a spark like a fire-bug . . ."

Even more detailed reports were obtained by the U.S. Weather Bureau during the period September 8, 1892, through September 30, 1894 (when its Station on Pikes Peak was closed). The results have been published in the *Reports of the Chief of the Weather Bureau* for 1893 and 1894. Of interest are the snowfalls recorded for the two years, September 1892 through August 1893, amounting to the enormous figure of 763 inches (19.4 meters); and September 1893 through August 1894, in the amount of 343 inches (8.7 meters). These Volumes also give readings of temperature, wind direction, and wind velocity for every hour of every day during the roughly 2-year observing period, an extraordinary collection of information. During the Weather Bureau occupation two persons were on duty continuously, with tours of duty each lasting two weeks (except when weather prevented relief from ascending the mountain). Special attention was paid to the correct design and emplacement of the snow gauge

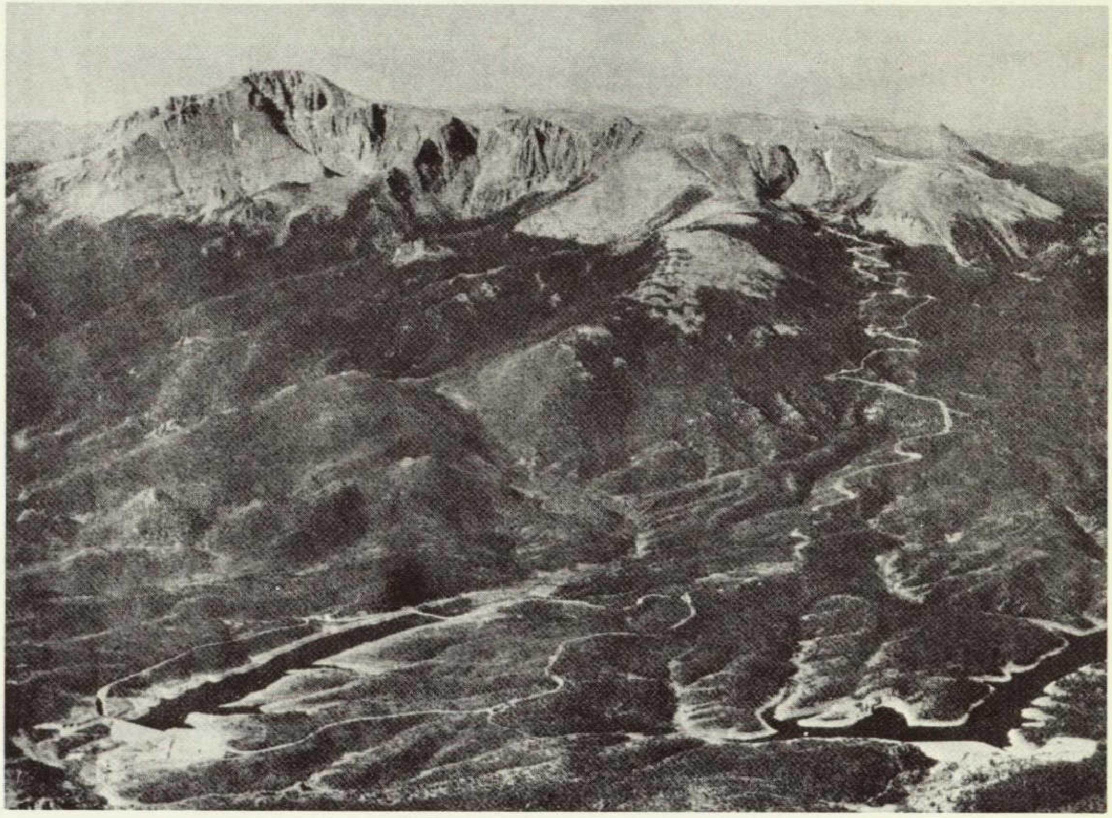


Fig. 22 Pikes Peak seen from the north. Crystal Creek and Catamount Reservoir, 5 and 6 miles from the Peak, in foreground as well as road leading to summit. Timberline about 11,500 ft.

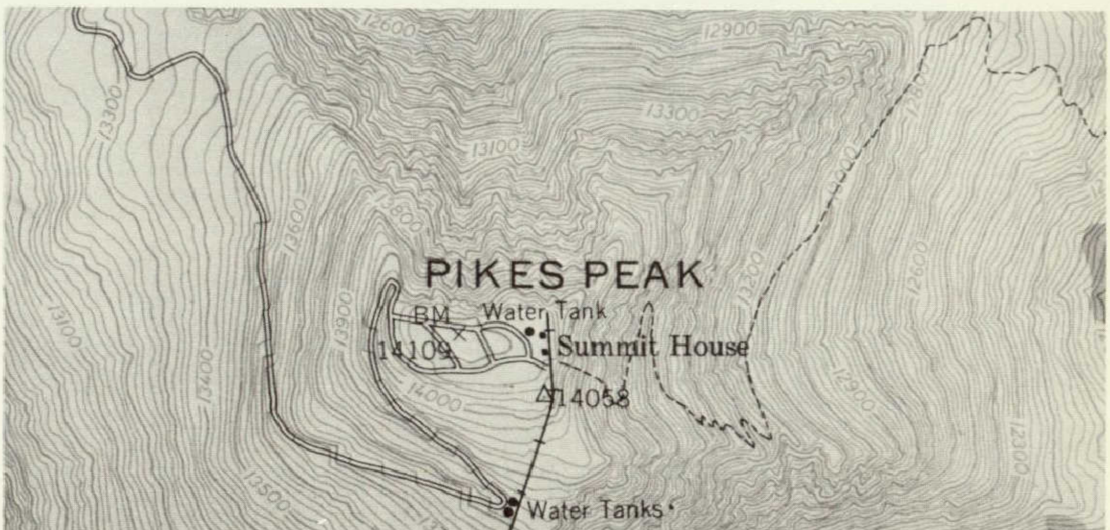


Fig. 23a Topographic map of Pikes Peak summit, contour interval 20 ft (1951).

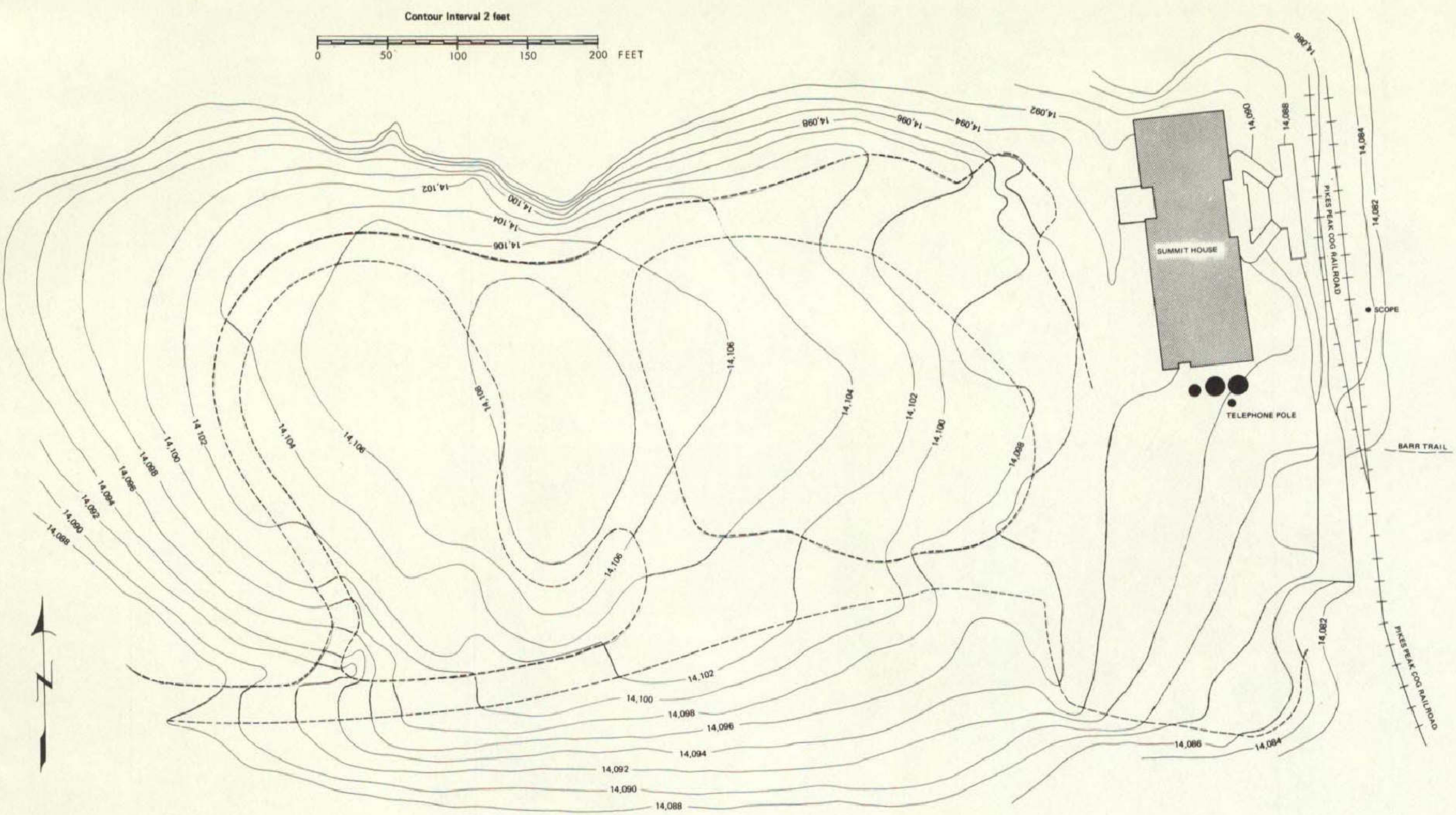


Fig. 23b Recent survey of summit, 2 ft contour interval. (Published with permission; prepared in 1970 by the Cartography Unit of the MITRE Corporation, Bedford, Mass. from the Dewerff-Meydrech (Pike National Forest Office) survey of 1965 and USGS quadrangle, 1:24,000, 1966).

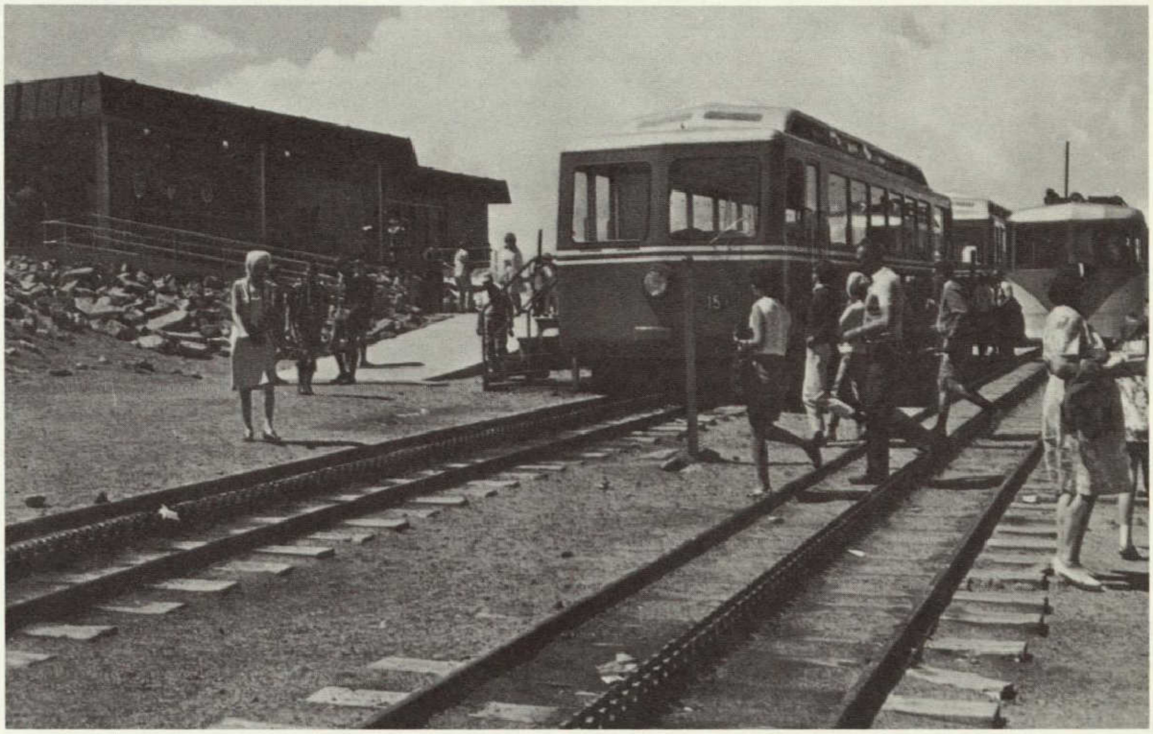


Fig. 24 Pikes Peak terminal station of diesel cog train (which climbs grades up to 25%).

Fig. 25 Glen Cove, April 1969, store and restaurant (no hotel), 11,500 ft, only facility on Pikes Peak Road.

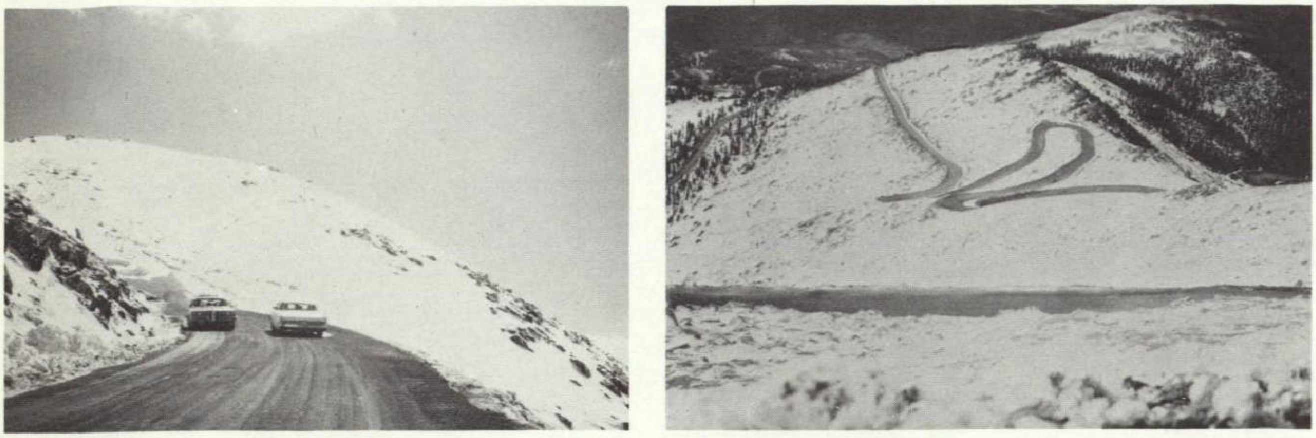


Fig. 26 Views of road near 13,000 ft level, not safe except in summer.

Fig. 27 Entrance gate of Pikes Peak National Forest; metal barriers discourage unauthorized entry.

Fig. 28 Pikes Peak Lab. of Fitzsimons General Hospital.

(*op. cit.* 1893, p. 232). This Volume also reproduces photographs of both the U.S. Signal Corps Station in 1885 and the U.S. Weather Bureau Station, 1892.

Dr. P. M. Kuhn of ESSA was able to add further to the Signal Corps and W. B. data from measurements made 1960–1966 under ESSA auspices in which maximum and minimum thermometers were used as well as thermographs. The results are given in Table IV. The frost points give an important check on the free atmosphere values of Table I. The measured 50 percentiles are on the average considerably *more favorable* (by about 1.4 times) than those in Table I; whereas the 10 percentiles are even more favorable than the 5 percentiles shown in Table I (by a factor of 1.6 on the average) so that the latter average 25-30 percentiles in reality.

I am also indebted to Mr. John D. Goodlette, Manager, System Engineering on one of the NASA projects of the Martin Marietta Corporation of Denver, for a discussion on the air flow around Pikes Peak. As President of the Soaring Society of Denver and an expert soaring-plane pilot himself, he has much personal experience with this circulation problem, as well as cloud conditions over Pikes Peak at different times of the year. He stated (April 1969) that between December 15 and February 15 the Peak is frequently clear, with temperatures at the summit level approximately 0°F (−18°C). With his letter of June 25, 1969, Mr. Goodlette sent a sketch which, with his permission, is reproduced in our Fig. 29 (vertical exaggeration 5-fold). The lenticular clouds referred to are of the type shown in Fig. 30, also due to Mr. Goodlette. He adds that the lenticulars rarely last longer than to about 10 p.m. local time, though he feels reasonably sure that the wave itself remains during the nighttime hours. These observations are obviously of great interest, not merely for IR observations, but astronomical image quality.

The frequency of condensation trails must be assessed in view of Pikes Peak's proximity to main line EW air routes. In daytime they are seen rather frequently.

TABLE III

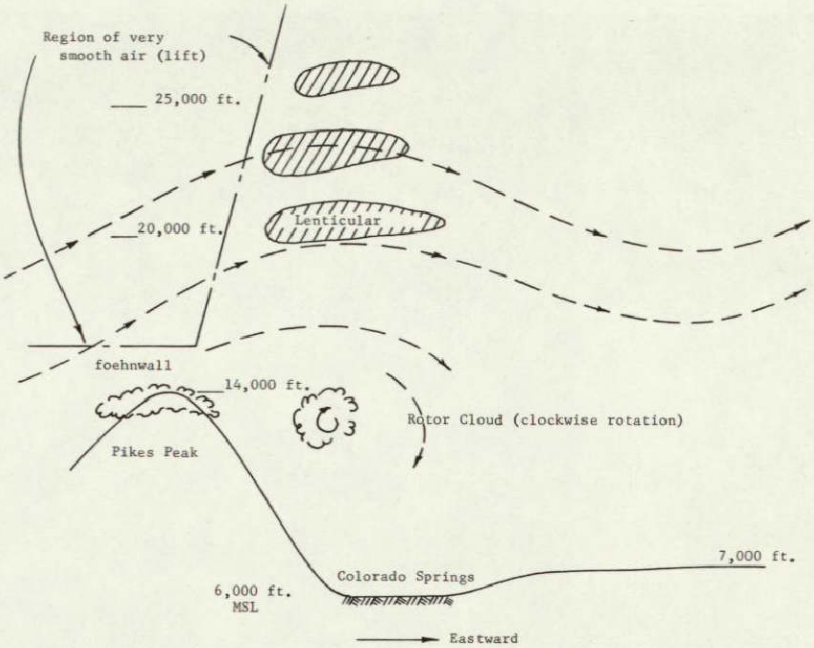
TEMPERATURES IN °C, MEANS AND EXTREMES, PIKES PEAK, COLORADO
1874–1888

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Daily Maximum		−13.1	−12.0	−10.0	− 6.3	− 1.2	4.9	9.1	8.3	4.1	− 2.0	− 8.6	−11.2	− 3.1
Average Daily Minimum		−20.1	−19.2	−17.0	−14.0	− 8.7	− 3.1	1.1	0.4	− 3.8	− 9.3	−15.2	−17.7	−10.6
Average Monthly, based on mean of Max. & Min.		−16.6	15.6	−13.5	−10.2	− 4.9	0.9	5.1	4.4	0.2	− 5.7	−11.8	−14.4	− 6.8
Extreme Maximum		− 1	− 2	6	4	8	17	18	17	13	14	2	− 1	18
Extreme Minimum		−38	−38	−34	−29	−22	−17	− 8	− 9	−14	−27	−38	−39	−39
Precipitation (inches)		1.56	1.39	2.11	3.78	3.68	1.77	4.46	3.92	1.77	1.41	1.84	1.49	29.2
Average Wind Movement MPH	$0\text{-}1^h$ A.M.	28.0	27.1	28.1	24.1	24.0	21.9	14.1	14.2	19.3	24.5	25.1	24.8	22.9
	$12\text{-}13^h$	26.2	22.9	21.7	17.2	17.7	16.0	9.4	9.4	13.0	17.2	22.1	22.3	17.9

TABLE IV

AVERAGE AIR TEMPERATURES AND FROST POINTS, 1960–66, PIKES PEAK
(COURTESY ESSA)

Months	Part of Record Used	T (Air)	T_f (Meas.)	T_f (Table I)	Completely Cloudy (day & night)	Nr. Obs. in 6 Yrs.
Dec - Jan - Feb	All	−16°C	−29°C	−23.9°C	23%	91
— — —	10% driest	−25	−39	−33.2	12	91
Mar - Apr - May	All	−11	−27	−21.3	28	120
— — —	10% driest	−21	−35	−27.8	12	120
Jun - Jul - Aug	All	7.5	− 9	− 8.6	81	83
— — —	10% driest	3.2	−18.5	−18.5	26	83
Sep - Oct - Nov	All	− 6.5	−20.5	−17.4	30	121
— — —	10% driest	−19.0	−30.0	−26.2	15	121



Notes:
1. Appearance of lenticulars and rotor depend on specific humidity distribution as a function of time and position. They form and disappear quite rapidly upon occasion. Rotor quite violent always because it is a vortex filament. It is always low, however, and should be out of LOS.
2. Foehnwall (cap cloud) is a spill-over of upslope fog when humidity allows formation of fog on westward facing slope.
3. Nights tend to be clear in absence of general winter frontal passage. Clouds seldom last beyond sunset + 2 hours. Westerly winds 20-50 knots are typical throughout diurnal cycle. Thermal heating during daytime can destroy a weak wave, but not a strong one.

Fig. 29 Vertical east-west cross section of atmosphere through Pikes Peak up to 28,000 ft, with explanatory notes (courtesy Mr. John D. Goodlette).

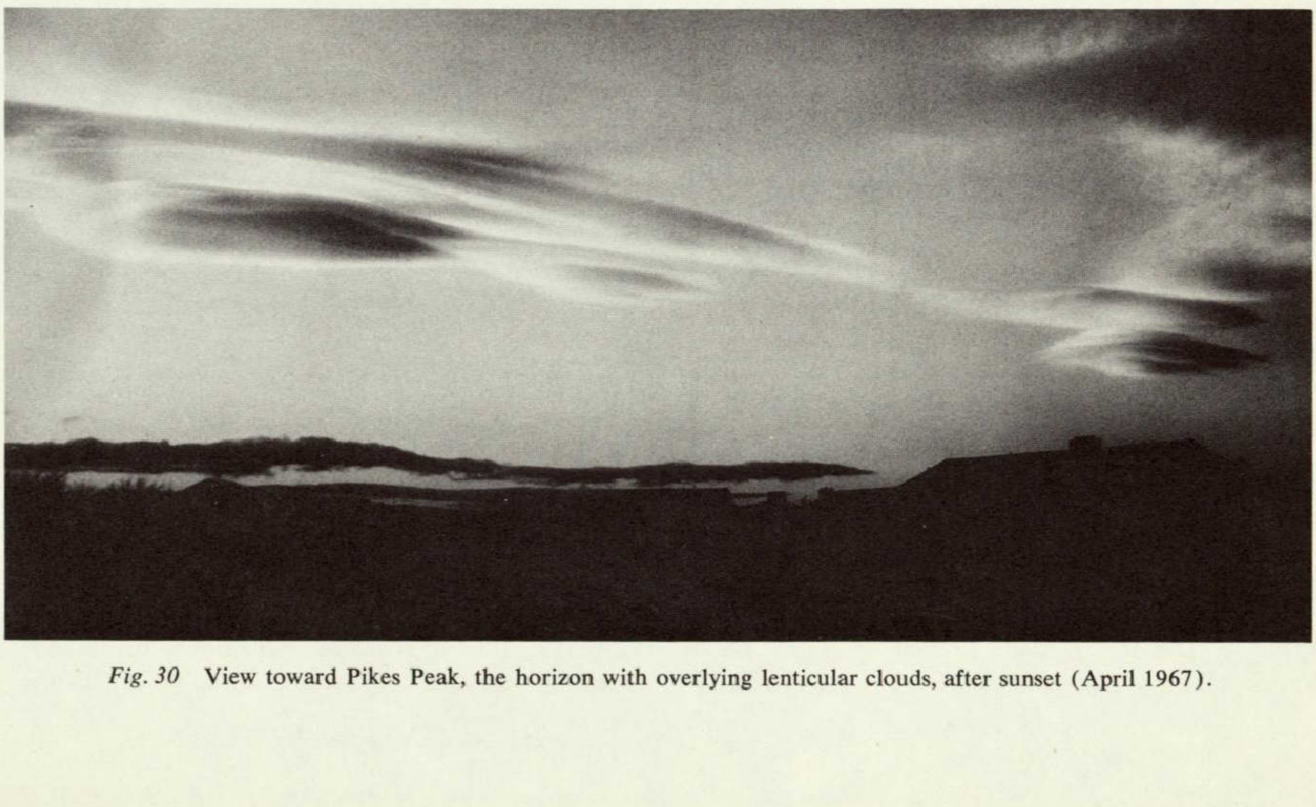


Fig. 30 View toward Pikes Peak, the horizon with overlying lenticular clouds, after sunset (April 1967).

Fig. 31 View of Mt. Rainier in background (just 100 miles from Mt. Hood in foreground), with Mt. Adams, 12,307 ft at right, and Mt. St. Helens, 9,671 ft at left. Columbia River behind dark land mass beyond Mt. Hood. July 30, 1968.

APPENDIX IV

Mt. Rainier, Mt. Shasta, Mt. Logan

Mt. Rainier, with its 41 glaciers and snow cover to low levels, is a magnificent mountain, dominating the entire State of Washington when seen from high altitude (as the writer had the privilege of doing several times from the NASA CV-990, Fig. 31). Fig. 32 shows the topographic map of part of Mt. Rainier; Figs. 33*a* and 33*b* show an aerial and a ground-based view; the former illustrates the effect of the volcanic heat on the center rim, referred to in the text. Conceivably, a cable-car line could be installed on Success Divide and Cleaver to Point Success (used in Table I). Reference is made to excellent photographs of Mt. Rainier in *National Parks of the West* (Sunset Books 1965).

Mt. Shasta in N. California also stands alone, at least 5,000 ft above any other mountain within a radius of 75 miles. Its topographic map is shown in Fig. 34. In summer its slopes are mostly bare (Fig. 35), and climbed by hundreds of people. Take-off point is the Sierra Club's Shasta Alpine Lodge, at 8,000 ft. The top is made in 6 to 8 hours, with descent taking 3 hours. There are five small glaciers on the N. and E. slopes: Whitney, over 2 miles long; Bolam, Hotlum, Wintun, and Konwakiton, 3–4 square miles together. The mountain is approached from the SW by the 16-mile Everitt Memorial Highway, ending at Panther Meadow, 7,500 ft high, where a modern winter-sport center has been built, Mt. Shasta Ski Bowl. A chair-lift starts there, operating in summer only, ascending to 9,212 ft (2,810 m), not quite high enough for useful IR work. At times Shasta causes a cloud street (Fig. 35) which normally appears to clear the summit level, but does indicate moist Pacific air at the lower levels. The approaches to Mt. Shasta, including airstrips, are shown in Fig. 36.

The apparently minor volcanic activity below the summit needs further investigation (Williams, 1932). There is a sulphur spring 200 ft below the highest point (Heald 1966). "The last eruptions probably occurred a couple of centuries ago, with a few feeble gasps as late as the 1850's." Mt. Shasta "has been reduced some 200 to 300 feet in altitude by erosion and its sides are seamed with ridges and canyons. The greatest erosion took place during the Pleistocene. The present rugged surface of the peak is the result of the grinding action of these prehistoric

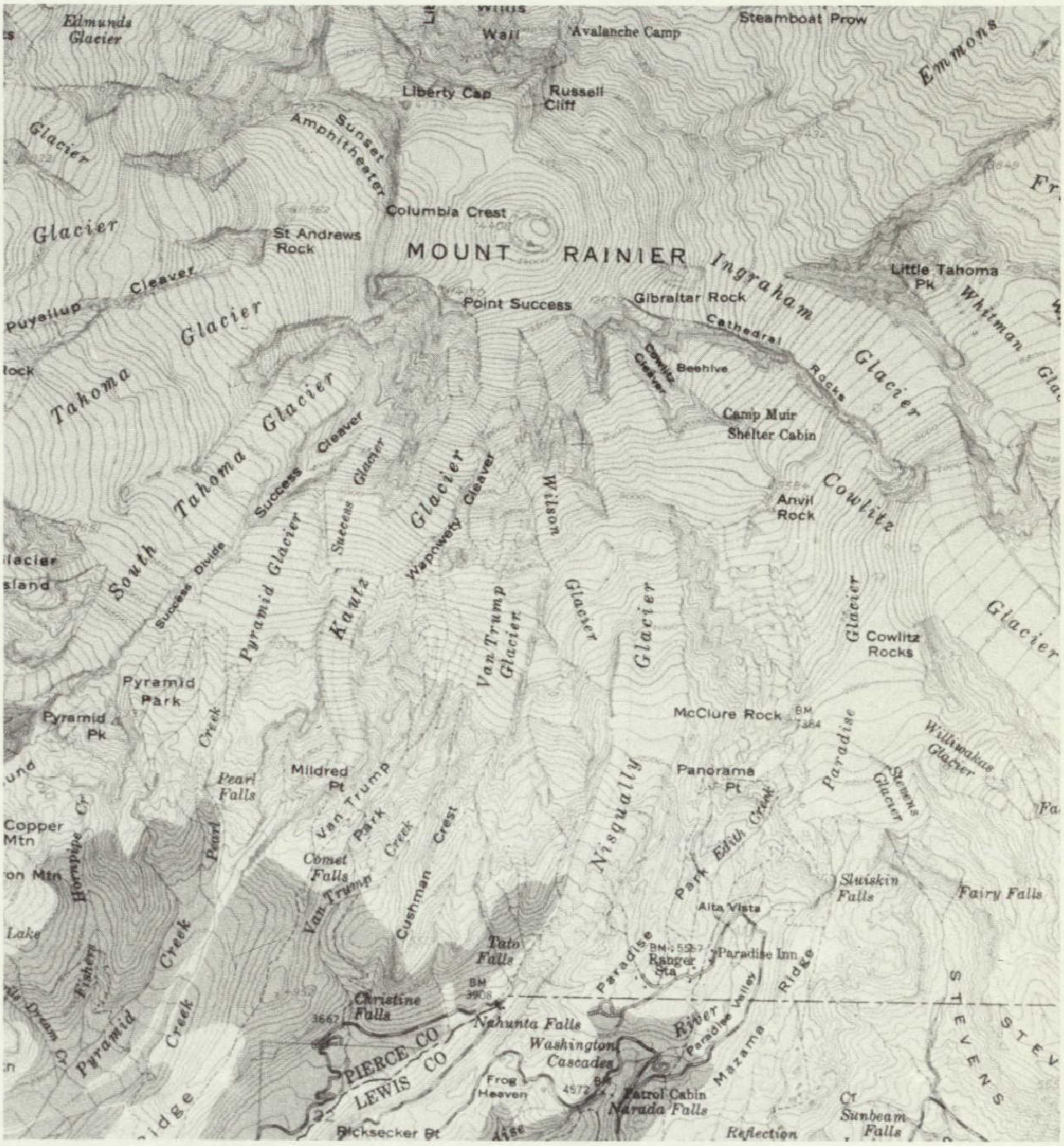


Fig. 32 Part of topographic map (scale 1:62,500) of Mt. Rainier. There are 41 glaciers between radial ridges consisting of exposed rock, on which cable-car towers could probably be built in summer.

glaciers. However, there are five glaciers still at work today putting the finishing touches on the steep upper slopes." (Heald, *op. cit.*).

With the much better general accessibility of Mt. Shasta, its much lower fractional sky cover, its comparatively minor volcanic activity, its more Southern latitude, and its much higher base, this mountain appears distinctly favored over Mt. Rainier as a potential site for IR observations.

After the above was written a most informative letter dated May 2, 1970, was received from Dr. Drummond Rennie, M.D., M.R.C.P., of the Department of Medicine, University of Illinois (Presbyterian-St. Luke's Hospital, 1753 West Congress Parkway, Chicago, Illinois) who during the past three years spent a large part of his time in the Himalayas, the Peruvian Altiplano and the St. Elias range of the Canadian Yukon. I had sent him a copy of the above manuscript, requesting comments and advice.

"I can think of several places that might be suitable in Peru, where the mountain weather is usually excellent from June to September . . . If you need long, clear *nights,* then this area is ideal because the mountain weather there is best during their winter. (The nights in the Himalayas in November and December are also excellent.) Ticlio, at 16,000

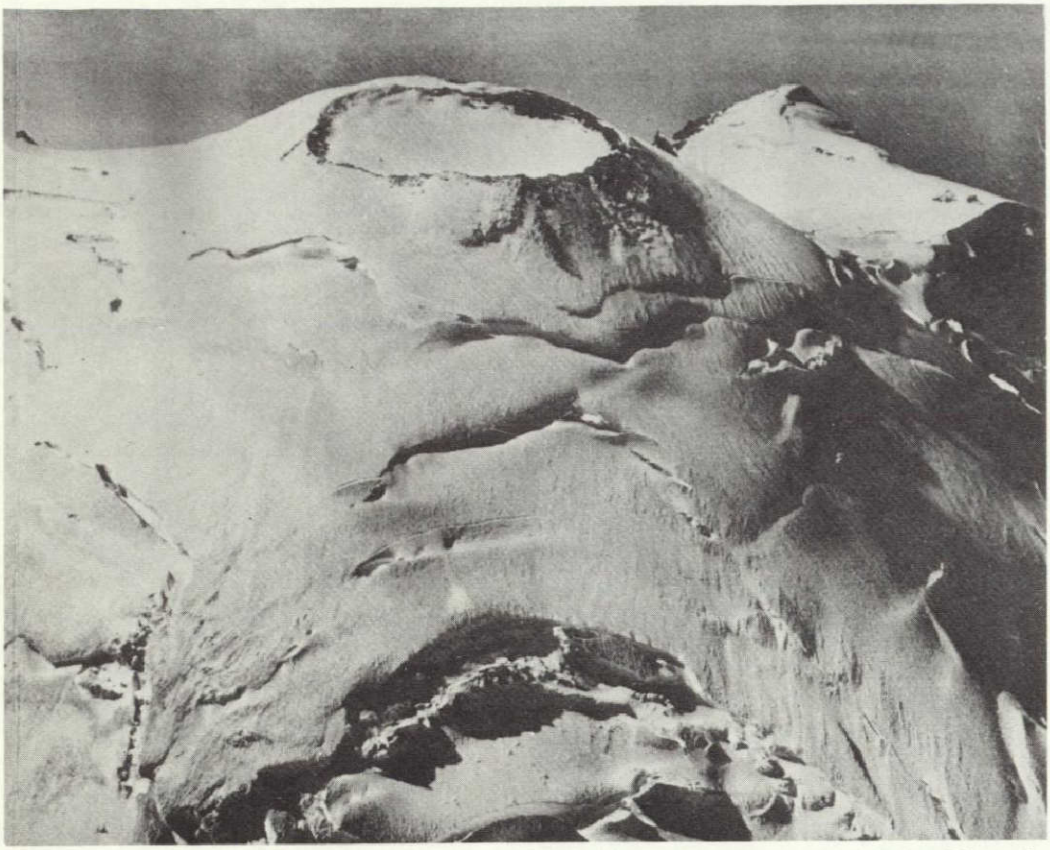


Fig. 33a Aerial view of the summit crater of Mt. Rainier, with ice cap and crevasses. Most of (in-part warm) crater rim and part of Pt. Success show exposed rock.

Fig. 33b Trail to Mt. Rainier.

Fig. 34 Mt. Shasta, from topographic map (scale 1:62,500).

Fig. 35 Cloud Street developed by Shasta (taken from NASA CV-990, returning from IR solar flight, July 19, 1968). Detailed coverage in Comm. No. 158.

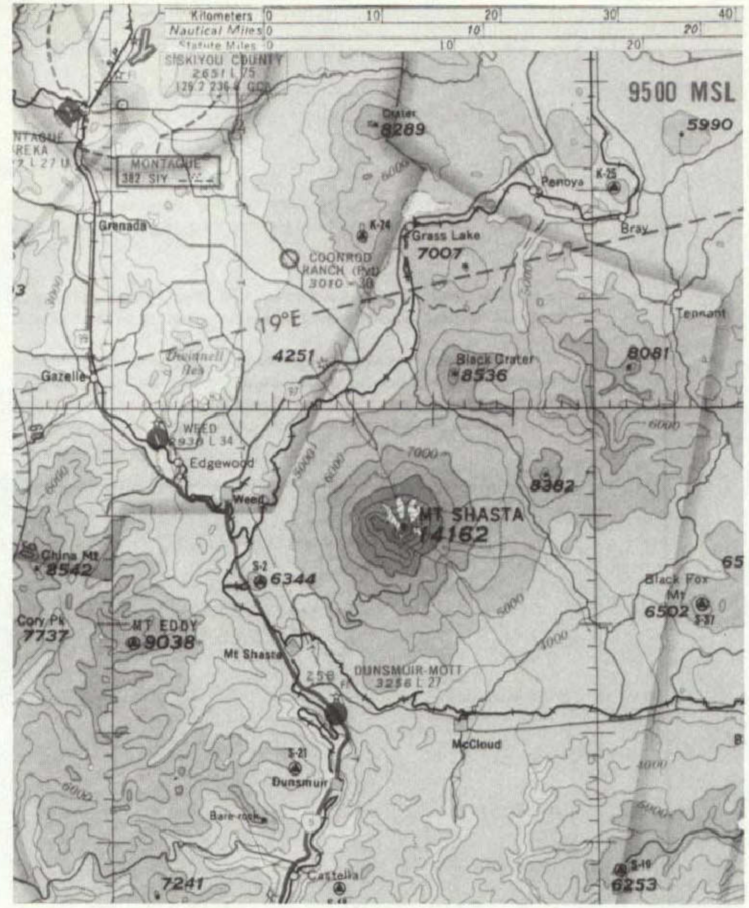


Fig. 36 Approaches to Mt. Shasta, by road, rail, and air (World Aeron. Chart).

ft, is 2½ hours from Lima by car, and already has rudimentary accommodation . . . The Cordillera Raura has distinct possibilities — and roads.

". . . The winters in Nepal are clear. The site of the Silver Hut (19,000 ft) on Ama Dablam near Everest, where a group of British physiologists spent 9 months, would be suitable but the logistics would be formidable . . . A helicopter could be arranged . . .

". . . My first choice would be Mt. Logan in the St. Elias range, Canadian Yukon. It has: (1) Height. The plateau where we have our facility is 17,600 ft high. The mountain is just under 20,000 ft, and a higher camp could be put up — at almost 19,000 ft. (2) Cold. (3) It is a going concern, with a base-camp laboratory on the Alaskan Highway. . . . Against it: it is, like McKinley, open for only one month a year (July) . . . Mt. McKinley in winter is definitely out.

"The facility at Logan is well run and well serviced. In particular, it has: (a) excellent rapid transport from base to mountain by Heliocourier plane; (b) plenty of physicians, physiologists and ancillary staff (climbers) . . . The staff will be able to supply very full meteorological data, all gleaned at the top of Logan over 3 years. At the moment, it is all on a rather small scale, and has been kept that way deliberately, to increase scientific efficiency . . .

"Finally, medical problems. If you acclimatise by going up in stages — no problem. We have all climbed above 20,000 ft, and as you know, several men *climbed* to 28,000 ft (in 1923) without added oxygen, on Everest. We have had some experience with the drug prophylaxis of acute mountain sickness, and would certainly be able to help there. Oxygen is supplied on Logan for those requiring it, as is power (propane generators) and heat. If much of your equipment is run by remote control, then you would need, perhaps, only one or two acclimatised people to run it. Perhaps the well-acclimatised climbers, who are all at college, or college graduates, could do this. They are in charge of all the meteorological work.

"More generally: the more slowly you ascend, the less the chances of developing acute mountain sickness, so that the ideal is to climb all the way, slowly. Practically speaking, few people are troubled by a sudden ascent to 10,000 ft, but thereafter problems tend to occur, the incidence being exceedingly variable.

"For many years, climbers have minimised their difficulties by climbing high, setting up a camp and then descending to the previous camp to sleep — 'climbing high, sleeping low' — but gradually moving up.

"There are now drugs available which are useful in speeding acclimatisation up, but it is very important to have a physician *experienced in the mountains,* and competent in physiology, around. *High altitude experience for the physician is essential* so that he does not panic and knows what to do.

"Your suggestion of mechanical transport to 8–10,000 ft, and spending a few days there before going higher is excellent; in my experience, *one* night at 10,000 ft has made it possible to work hard, and sleep well, at 14,500 ft, thereafter I myself have gone straight from sea level to 17,600 ft and have conducted 10 days of research before coming down, but this is not a good idea.

". . . With a competent physician, staged acclimatisation, efficient transport, drug prophylaxis, and available oxygen, there should be no danger."

In view of Dr. Rennie's most interesting comments we have added in Fig. 10 the "equivalent" water-vapor distribution computed for Mt. Logan at the accessible 500-mb level (about 5580 m or 18,300 ft), using the 500-mb graphs in the Gringorten *Atlas* for July (when Mt. Logan is accessible) and January (so far not considered accessible). It is seen that the July conditions on Mt. Logan are not appreciably drier than Mt. Shasta would be for the nine *non*-summer months. Nevertheless, the possibility of IR astronomical observations from Mt. Logan appear a challenge, certainly as long as Mt. Shasta is not accessible in winter. Professor Charles S. Houston, Chairman of the Department of Community Medicine, University of Vermont, in charge of the physiological program at the Mt. Logan facility, adds the following pertinent information regarding it (letter May 18, 1970): "The Mt. Logan Laboratory at 17,500 ft has been occupied for two months each summer since 1967. It consists of a wooden shelter, now about 20 ft beneath the surface of the snow, which is used as a store room and housing for the generator. In addition, several temporary buildings are erected each year on top of the snow. These are dome-shaped, double-wall nylon shelters with plywood floors, and, with space heaters and electricity, provide comfortable living and working quarters.

"The Laboratory is supplied by a small aircraft which lands on the snow with skis, and is based 90 miles away at 2,000 ft, where it lands on a gravel strip with wheels. Helicopter backup has been demonstrated to be feasible, and is available. The pay load for each type of aircraft is around 500 pounds. We have successfully completed several air drops from much larger aircraft.

"The facility is located on a permanent snow field, which seldom melts. Summer temperatures range from -10 to $+15°$ F. Snow and white-out occur about 25% of the time or less. Good weather is impressively clear though I do not have the weather records with me, which are kept every four hours, day and night, all summer; my recollection is that the relative humidity is extremely low.

"The facility is occupied during the two months by eight climbers who provide a support party for the five scientists and ten experimental subjects who come up in shifts from the base camp for acute studies. The acclimatized individuals have little difficulty; those exposed acutely experience various degrees of mountain sickness the first few days."

The entire program is under the auspices of the Arctic Institute, a combined Canadian-U.S. operation. The U.S. address is 1619 New Hampshire Avenue, N.W., Washington, D.C., 20009; the Canadian address: 3458 Red Path Street, Montreal 109, P.Q.

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No. 143 THE PLANET MERCURY: SUMMARY OF PRESENT KNOWLEDGE

by GERARD P. KUIPER

February 4, 1970

ABSTRACT

Present knowledge is collected on the Mercury orbit, diameter, mass, density, rotation, surface features, atmosphere, polarization, albedo, and color. Comments are presented on problems that may be solved from image resolutions of about 1 km.

1. *Orbit*

The mean orbital distance *a* for 1968 is 0.387099 astr. units *; the eccentricity *e,* 0.205628; and the inclination *i,* 7°.00415. The quantity *a* varies little except for minor periodic terms; *e* varies during several million years from 0.109 to 0.241; *i* (counted with respect to the invariable plane of the planetary system) varies from 4°.5 to 9°.8; while the longitude of the perihelion and the longitude of the ascending node on the invariable plane rotate in periods of respectively 220 and 250 millennia (Brouwer and Clemence 1961). (To these, small relativistic effects must be added.) A plot of the time variation of *e* and *i* for 10^7 years centered on the present epoch, and based on the theoretical analysis by Brouwer and van Woerkom (1950), kindly provided by Drs. E. C. Hubbard, C. Oesterwinter, and C. J. Cohen, is appended. It is unknown how much *a, e, i* may have varied through the *entire* age of the solar system, 4.6-4.7 10^9 years; it is possible that the variations have not been vastly larger than during the past "several million" years for which the perturbation theory is known to be approximately valid.

2. *Diameter, Mass, Density*

From micrometric observations and disk-meter measures, particularly during Mercury transits across the solar disk, a diameter of 0.38 Earth was derived. Recently a much more precise radar measure has been obtained (Ash *et al.* 1967), 4868 $\pm$ 4 km, or 0.382 Earth.

The first fairly accurate value of the mass was derived by Rabe (1950), 0.0543 Earth $\pm$ 0.7%. Improved values were derived (Ash *et al.* 1967) from radar data and by Mulholland (1968) from Mariner V signals, of $6{,}021{,}000^{-1}$ Sun or 0.0553 Earth $\pm$ 0.9%, and $5{,}935{,}000^{-1}$ or 0.0561 Earth, respectively. We may therefore conveniently adopt the old Newcomb (1895) result since then used in the Nautical Almanac, $6{,}000{,}000^{-1}$ Sun or 0.0555 Earth $\pm$ 1%.

The resulting mean density of the planet is 1.01 Earth or 5.6 cgs $\pm$ 1%. Because of the small mass of Mercury (small gravitational compression), it may be directly compared with the uncompressed density of the Earth, 4.2; of Mars, 4.0; and of the Moon, 3.3. There is thus no doubt that density and therefore composition differences of the terrestrial planets are *real,* and that the assumption of near-equality in composition is erroneous. Mercury is composed of 65°-70% by weight (half the volume)

* The astr. unit is 149,597,892 $\pm$ 1.5 km (Muhleman 1969).

1) Paper presented at CalTech Mercury Symposium, February 4, 1970.

of metal phase; and only some 30% by weight of silicate phase.

Two explanations may be advanced for this extraordinary composition.

(a) The accretion process favored the acquisition of metallic constituents, even for the Earth which appears to be more iron-rich than the Sun. This possibility has been examined by Harris and Tozer (1967). Iron can also accrete preferentially at higher temperatures (Anders, 1968).

(b) The planet Mercury was originally 2-3 times more massive, melted internally, resulting in the formation of a metal core and a silicate mantle, all prior to the occurrence of a very luminous phase of the Sun, as postulated by Hayashi (1966), which was responsible for the evaporation to space of most of the silicate mantle.* The discovery of observational evidence for the Hayashi phase of the Sun, either from the surface of Mercury or the surface of the Moon in a comparatively undisturbed highland region (such as exist between Tycho and Snellius; Kuiper, 1954 and 1959), would, of course, be of very great interest for charting the early evolution of the solar system.

A choice between processes (a) and (b) could perhaps be made now. E.g., an interpretation of the dark spots on Mercury (as lava fields) would favor process (a); and a more detailed study of the accretion process in the solar nebula near Mercury could be made with the solar luminosities suggested by Hayashi (1966), but a time scale *extended* to allow for the considerable angular momentum of the solar nebula, neglected in the studies to date.

3. *Rotation*

Visual observations of the planet and its spots since Schiaparelli (1890) showed that the period of rotation was *not* short (about a day), but *long*, possibly as long as the orbital period, 88 days. Because of the known synchronous rotation of the Moon and the Jupiter satellites, it probably did not occur to anyone that the long period could be anything but synchronous. Proximity of Mercury to the Sun fitted with this concept. The discovery by radar of the period, 59 days $\pm$ 3 (Pettengill and Dyce 1965; Shapiro 1967), ⅔ of the orbital period, was, of course, of extraordinary dynamical and cosmological interest. It led to a series of theoretical studies (Colombo and Shapiro 1965; Peale and Gold 1965; Colombo 1965; Goldreich and Peale 1966), showing the conditions required for this type of synchronization. The considerable eccentricity of the orbit and the resulting near-synchronous rotation near perihelion (when tidal friction is largest) seem to suffice, but do not exhaust all questions relative to the evolution of the system; cf. also Kaula (1968). In particular, the large secular variations in the orbital eccentricity pose problems.

4. *Surface Features and Rotation*

With the rotation period known to a few percent, all visual and photographic observations of the past 75 years could be re-examined and combined into one map. This task was undertaken by Camichael and Dollfus (1968) who added important observations of their own, made under the excellent conditions of the Pic du Midi, France. On the basis of all the reliable drawings and photographs, they concluded that the period of rotation is, within a precision of better than $\pm$ 0.01 days, indeed just ⅔ of the orbital period, 58.646 days. The resulting map, drawn on the Mercator projection, is reproduced in Fig. 1 (South up). This map may be compared with a map of Mars drawn by J. Focas, also at the Pic du Midi, in 1958, probably the most reliable and detailed map of Mars derived from earth-based observations (cf. Fig. 2). It may further be compared with a similar map drawn for the Moon, composed at this Laboratory by Mrs. B. Vigil * (Fig. 3), and with maps of the Galilean satellites of Jupiter drawn by Lyot (reproduced in Fig. 4) (telescopic views: South up). While intercomparison between these maps is hampered by the low resolution in Figs. 1 and 4, some conclusions may be drawn. A suitable working hypothesis appears to be that all dark areas on the Moon, Mars, and Mercury are lava fields. For Mars this hypothesis was discussed previously (Kuiper 1957); it appears compatible with seasonal and progressive changes in visibility, attributable to moving aeolian deposits (*loc. cit.*). Some areas on Mars, like the Solis Lacus region, appear remarkably similar to the Mare Australe region on the Moon. The Mercury spots seem more Mars-like than lunar; the bulbous appearance of the lunar spots, attributable to impacts, appears absent or minor. The bright areas of Mercury might, in part, be due to crater ray systems.

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* The writer reviewed this possibility in a lecture before the A.G.U., Washington, D.C., April 1969.

* The coordinate system used is that of the recent ACIC map, using the Mercator projection; the half tones are based on available photography.

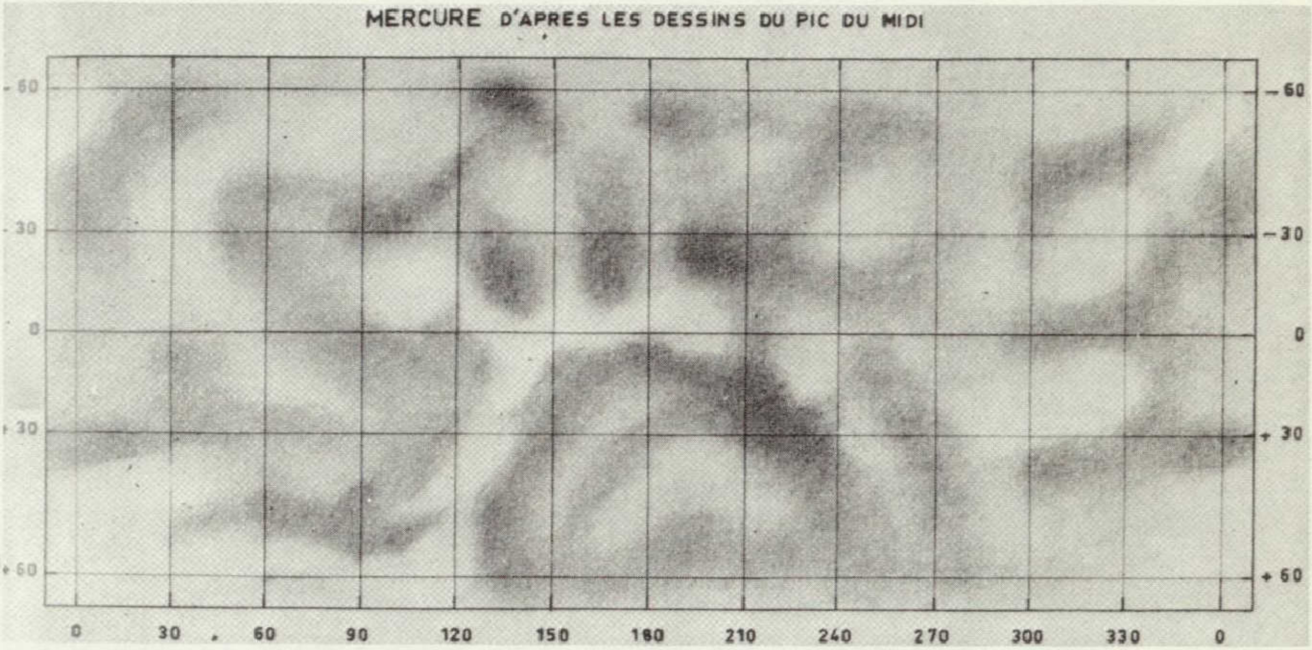

Fig. 1 Mercator map of Mercury spots, *S* up (after Camichel and Dollfus 1968).

5. *Atmosphere*

Early attempts of deriving information on the presence of an atmosphere on Mercury from polarization measurements near the cusps of the planet were reviewed by O'Leary and Rae (1967) and found to need revision. They concluded that the polarimetric observations suggest an upper limit of 1 mb for the surface pressure, while the similarity of the polarimetric and photometric properties of Mercury and the Moon suggested an upper limit of 10^{-5} mb. The earlier results were also criticized by Hodge (1964).

Direct spectroscopic tests include those of Moroz (1965) who believed to have found CO_2 in the amount of 0.3-7 gm/km^{-2}; Binder and Cruikshank (1967) who found no evidence for the presence of CO_2 on Mercury from spectra in the 1.6 μ region; Belton, Hunten and McElroy (1967) who observed the 1.049 μ band and placed the upper limit of 5 m-atm of CO_2 on the planet, equivalent to a surface pressure less than 0.35 mb; Bergstralh *et al.* (1967) who used the 1.2 μ bands and derived an upper limit of 0.58 m-atm or a surface pressure of 0.04 mb; and Kuiper, Cruikshank, and Fink (1970) who observed the planet between 1μ-4μ and found an upper limit for CO_2 of 0.01 mb. Yet CO_2 would probably be the first gas to look for in view of the composition of the Mars and Venus atmospheres. Radiogenic A^{40} would be much harder to detect.

The low temperature occurring on the dark side of Mercury, approximately 100°K, and the much lower temperatures that must exist in shaded areas and crevices near the Mercury poles, must act as cold traps which will reduce the CO_2 pressure to amounts that are imperceptibly small spectroscopically. E.g., for 80°K the surface pressure would be 10^{-7} mb for CO_2 and 10^{-22} mb for H_2O; for A^{40} the saturation pressure would be 400 mb so that small amounts of radiogenic argon could possibly be present.

6. *Polarization, Albedo, Color*

As is well known, these three quantities are remarkably similar to the Moon. For polarization we refer to the classical work of Lyot (1929) who showed that the Mercury polarization curve is intermediate between those of the waxing and waning phases of the Moon (which differ slightly, owing to the uneven distribution of lunar maria). The visual albedo of Mercury is 7% (like that of the Moon); and the color is remarkably similar as well. Harris (1961) cites $B - V$ for the Moon +0.92 and for Mercury +0.93, as compared to the solar value +0.63. Results for the full spectral range of 0.31 to 1.0 μ are given by Irvine *et al.* (1968), together with a plot of lunar values by Harris. The agreement is very close. Presumably, the Mercury surface is covered, as is the case for the Moon, with finely-

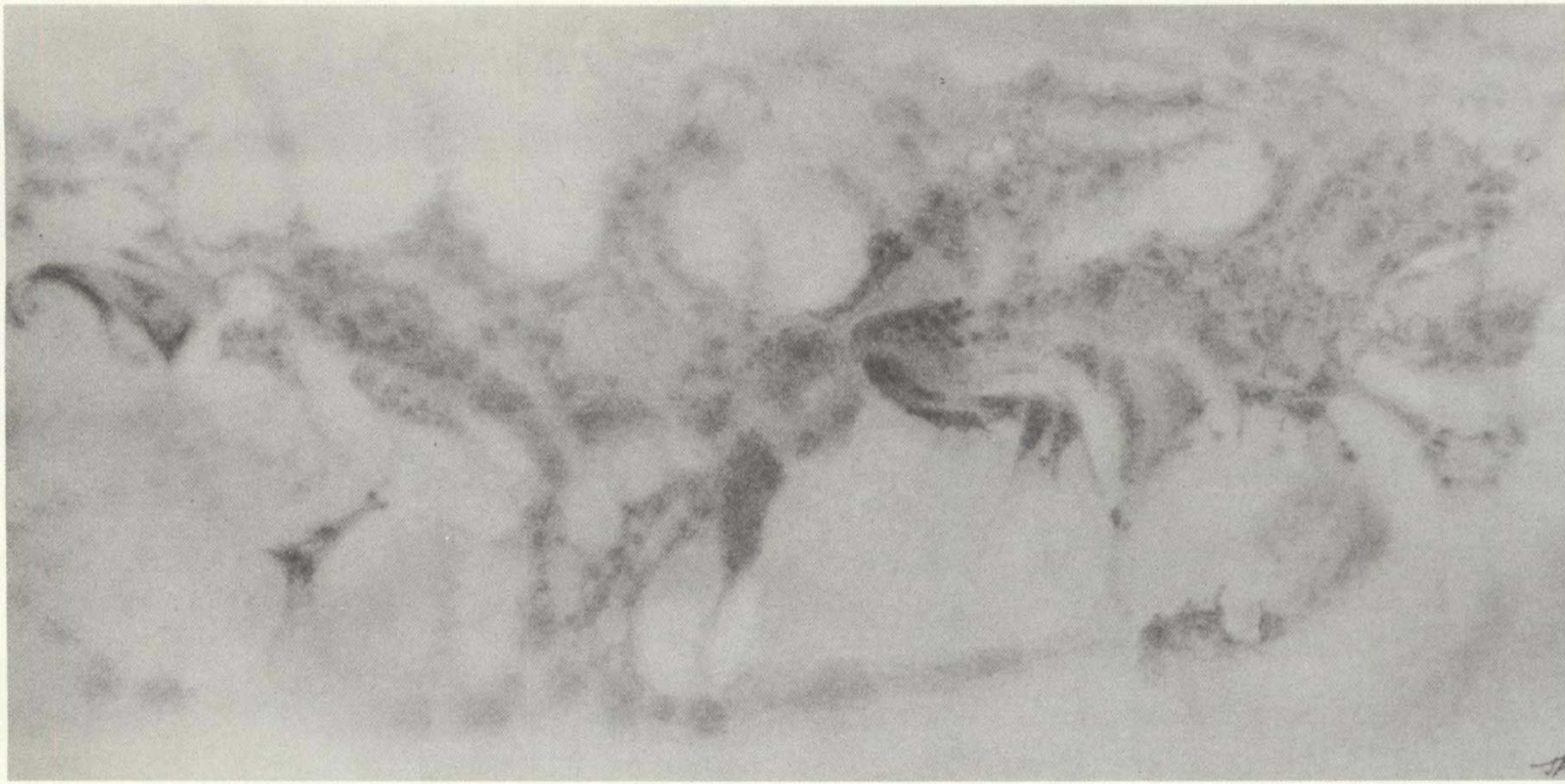

Fig. 2 Telescopic Mercator map of Martian surface features, *S* up (after Focas in Dollfus, *Planets and Satellites*, Ch. 15, 1961, Plate 19).

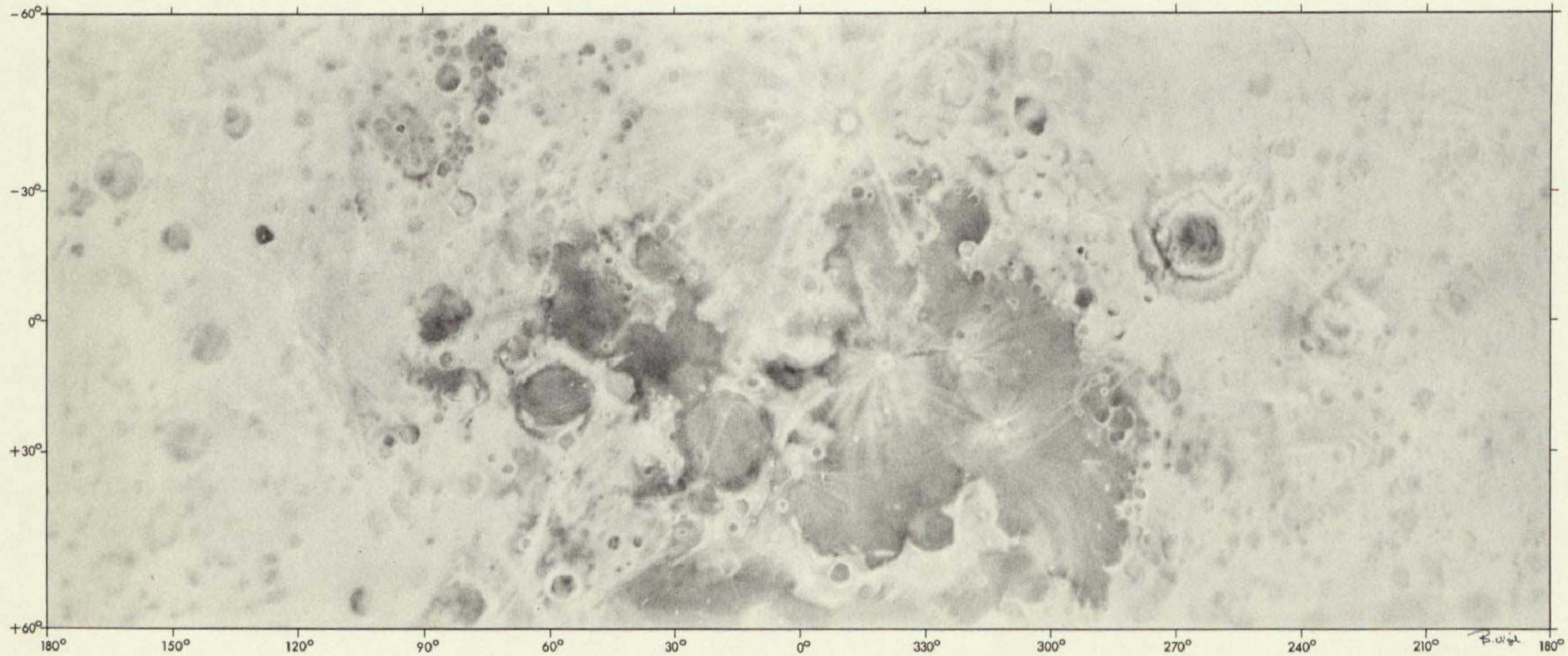

Fig. 3 Mercator map of Moon, *S* up, by Barbara Vigil.

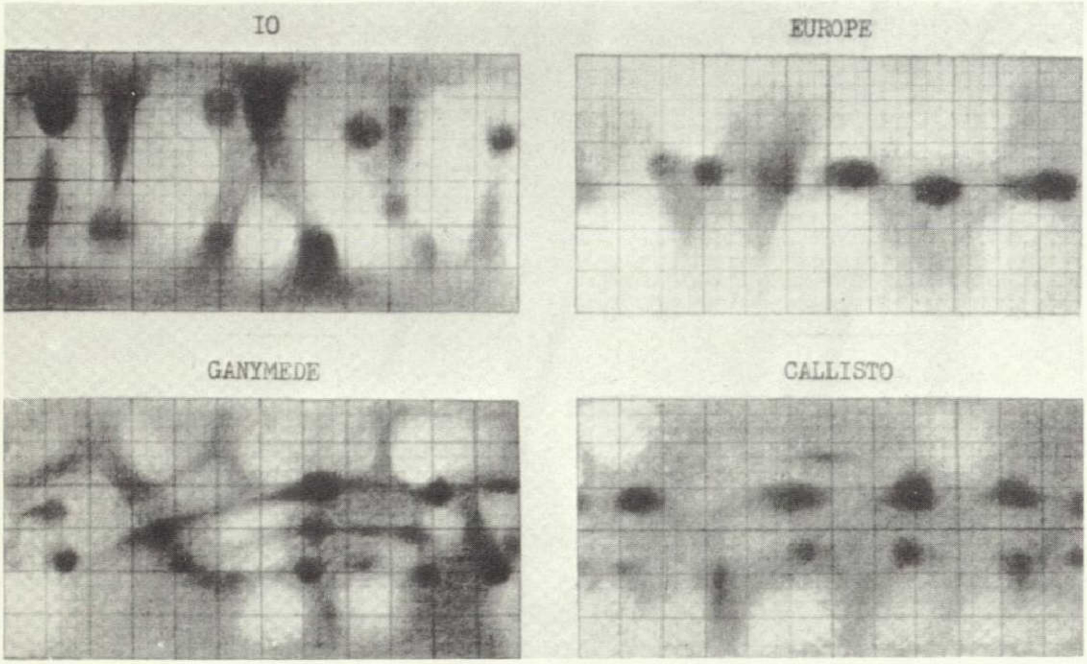

Fig. 4 Mercator map of Jovian satellites (after Lyot, *Planets and Satellites,* Ch. 15, 1961, Plate 40).

crushed silicate material, roughly basaltic in composition.

The radar cross section (or radar geometric albedo) measured at 70 cm (430 Mc/sec) is 6-7% of the physical cross section, as compared to 7% for the Moon (Pettengill *et al.* 1967); and the scattering law is also very similar to that of the Moon. These authors point out that similar radar cross sections have been found at other observatories for 700, 1295, and 2388 Mc.

7. *Craters and Debris Layer*

Owing to the smaller distance of Mercury from the Sun, compared to the Moon, of 0.4 a.u., the energy of impact by small asteroidal masses of very large meteorites will approach 2.5× the energy of corresponding lunar impacts. This ratio, 2.5×, might also apply to smaller meteorites that spiral in toward the sun by the Poynting-Robertson effect (since all relative motions are scaled up between pairs of orbits of given eccentricities).

With the increased energy of impact, the crater area per impact will be approximately $(2.5)^{2/3} = 1.8\times$ that on the Moon. The frequency of meteoritic impacts, however, will be *reduced,* compared to the Moon, by a factor $> 10\times$ (Arnold 1964) for the same dynamical reason that the Martian impact rate is some 20 times larger than the lunar rate (cf. Anders and Arnold 1965; Witting, Narin, and Stone 1965; Öpik 1951 and 1963; Kuiper, Strom, and Le Poole 1966). As a result craters on Mercury of asteroidal (meteorite) origin will be comparatively rare, $> 10\times$ less frequent than on the lunar maria. Cometary craters, like Tycho on the Moon, may have comparable frequency on Mercury since they are expected to be produced by near-parabolic comets (Kuiper 1965) whose impact frequency per unit area will not vary greatly in the inner parts of the solar system. A few large ray systems on Mercury may therefore be expected. Very small craters ($d < 10$ meters) might be *formed* more frequently on Mercury than on the Moon; but the disturbed (debris) layer, approximately 1 meter thick on the Moon (predicted, Öpik 1960; observed, Kuiper 1965) is likely to be somewhat thicker on Mercury, both because of the greater density near the planet of the Zodiacal Cloud and the high eccentricity of the Mercury orbit; and this "weathering" will have *destroyed* older small craters. The thicker debris layer and the much smaller frequency of large craters may account for the smoothness of the planet as derived from its radar returns.

8. *Expected Program of Surface Interpretation*

Because of the numerous close parallels between the Mercury surface and that of the Moon, cited above, some forecasts can be made regarding the stages of exploration which will follow the acquisition of pictures with 1 km or better resolution. This kind of resolution resembles modern telescopic resolution of the Moon, so that the history of lunar exploration might, in some measure, be repeated for Mercury.

Telescopic observation of the Moon, visual and photographic, sufficed for arriving at the modern interpretation of the lunar maria, including their approximate ages of the flooding (Kuiper 1954 and 1959) and the recognition of overlapping lava flows, most clearly observed on Mare Imbrium. The lunar maria were found to belong to two classes: impact maria which partially or nearly completely flooded with endogenic lavas (not caused by the impact but supplied from the interior); and flooded low lands, not obviously caused by impacts. The lunar impact maria are surrounded by mountainous walls (Baldwin 1949). Further studies disclosed that additional concentric mountain rings are often present, forming roughly geometric progressions in radii (Hartmann and Kuiper 1962). It was further found that the times of flooding were delayed with respect to the impacts causing the basins, by thousands or possibly hundreds of thousands of years, different for different basins. This was shown by the numbers of fairly large impact craters formed on the inside sloping walls of the basins before the flooding occurred.

The lunar craters fall into three broad categories: early pre-mare, with no central peaks; late pre-mare, with central peaks whose volumes depend upon the depth of the crater floor; and post-mare, with whitish, small, multiple central peaks. The central mountains appear igneous in nature. This sequence of events appears to be the direct result of the timing of the impact with respect to the period of maximum melting on the Moon (Kuiper 1954). Related to this is the isostatic adjustment of pre-mare crater floors from the original concave to convex, clearly the result of subsurface melting.

A number of important discoveries regarding the lunar surface were made during the past decade, after: (1) 3 orders of magnitude in resolution were gained during the Ranger VII, VIII, and IX missions; (2) another 2-3 orders of magnitude from the pictures returned by the soft-landers (Surveyor and Luna 9); and direct tests of the bearing strength of the surface became possible as well as direct chemical analyses from α-scattering experiments, showing that the lunar maria were indeed essentially basaltic in composition, as inferred from telescopic observations; (3) the entire lunar surface was recorded with moderate- to high-resolution by the Orbiter series; and (4) when the climax was achieved in 1969 by manned landings and the return to Earth of lunar surface materials, with the resulting enormously-expanded information on isotope chemistry, trapped gases, ages, and the structure of lunar rocks and surface debris (*Science* 1970).

Considering the possibility of 0.1-1 km resolution for Mercury, only the lunar Ranger and Orbiter records need to be considered for comparison in addition to Earth-based photography (resolution 300 meters). The Ranger records demonstrated the existence of extremely numerous collapse depressions in lunar lava fields (size range mostly 30-500 meters, with some depressions, e.g., on the floors of Ptolemaeus and Hipparchus even larger and visible telescopically). Also discovered by Ranger were the first lunar rocks, up to a few meters in diameter, and allowing a determination of an average bearing strength of the upper ½ meter of the lunar surface (approximately 1 kg/cm^2; Kuiper, Storm, Le Poole 1966). The Ranger records showed that the lunar grid system was traceable to the meter scale which meant that the thickness of the debris layer was of the order of 1 meter. The Orbiter records added much information on lunar rilles substantiating conclusions from ground-based observations that the sinuous rilles are old lava channels (Strom 1966). Also, the Orbiter records for the first time clearly demonstrated the existence and extent of induced volcanism resulting from the Tycho impact, with numerous lava lakes and lava flows found on the outer slopes of a crater that by all accounts is comparatively recent. Earth-based photography of the Moon at full phase sufficed to show sharply bounded color provinces (Whitaker 1965) which in several cases could be interpreted as due to discrete lava flows. A similar approach is likely to be productive for the planet Mercury.

Mercury observed with 0.1-1 km resolution would give quite satisfactory outlines of the maria and of the highlands between, but will probably not show rocks. It would be interesting to discover whether on Mercury any true impact mare exists, with near-circular mountain walls. The answer may well be negative, with only flooded maria present, as Mare Nubium on the Moon (and presumably most of the maria on Mars); because the impact maria on the Moon are almost certainly due to circumterrestrial bodies, not small asteroids (Kuiper 1954), which struck the Moon with high frequency during a

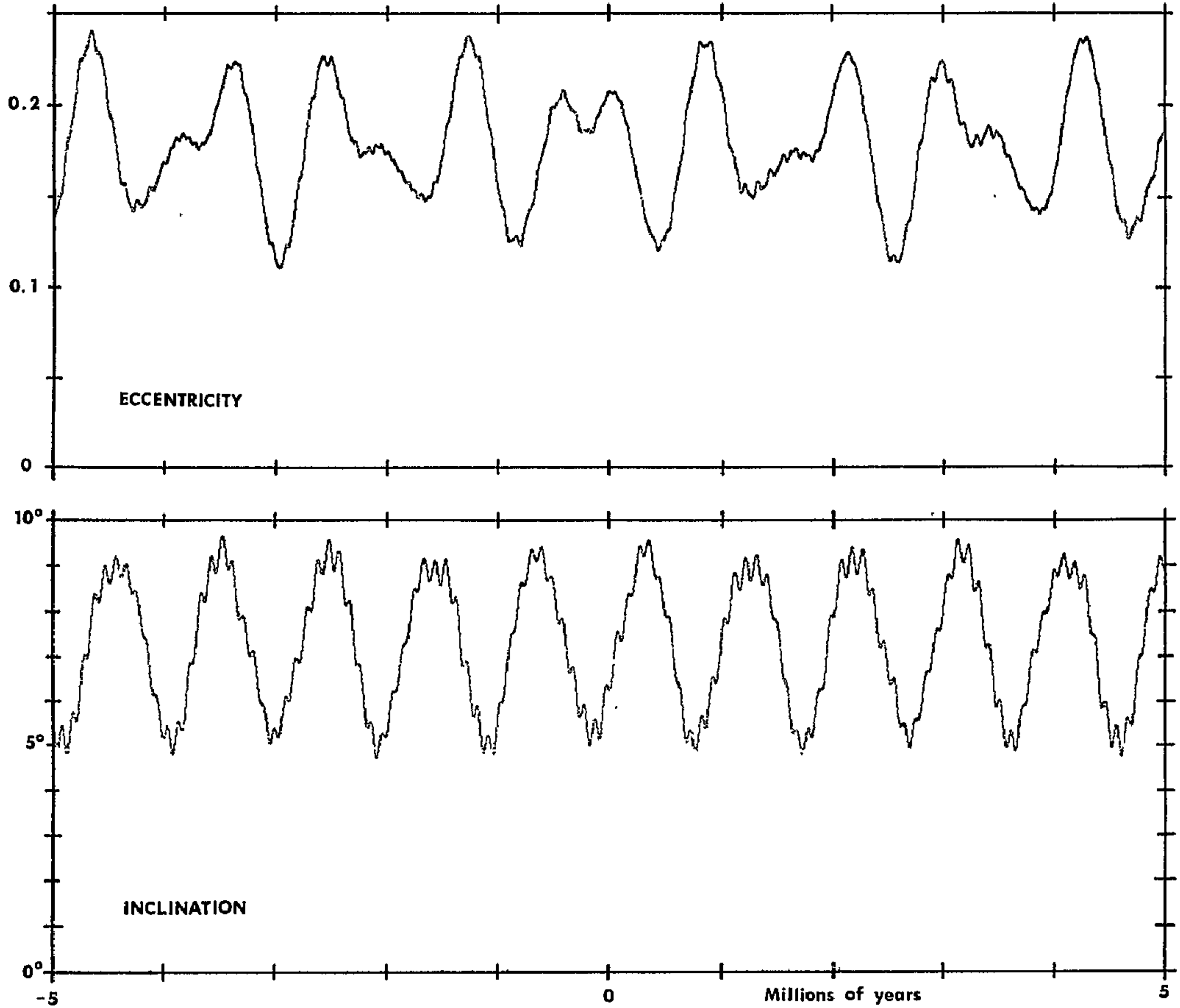

Fig. 5 Time variation of orbital eccentricity and inclination of Mercury (with respect to invariable plane) for 10,000,000 years centered on present (courtesy Hubbard, Oesterwinter, and Cohen, in press).

very limited period of time, roughly coincident with the period of maximum melting. Both the frequency- and size-distributions of craters will be of interest, with the frequency expected to be far below that on the lunar maria, and with the cometary/asteroidal impact ratio quite different from the Moon or Mars. Rilles or graben may be present as on lunar maria, inside and roughly parallel to the shore lines. A grid system on Mercury would be expected only if the original rotation of the planet were much faster. There may be some evidence for "weathering" by subsequent impacts and temperature variations, but with 1-km resolution these effects may not be conspicuous since there will be no aeolian deposits as on Mars. A few large ray craters of the Tycho or Copernicus type and more smaller ones may be present, unless a rapid surface turnover by micrometeorites would obliterate the rays themselves in 10^8-10^9 years or less. Evidence from the light-colored areas for a period of high surface temperature would be of extraordinary interest. Major mountain systems not related to the maria are not expected for a body, not much larger than the Moon, on which continent formation has probably not occurred; nor may there be much evidence of volcanism other than directly associated with the original mare deposits and high-velocity impact craters (such as Tycho). However, Mercury may present great surprises.

Not discussed here are interactions between the planet and the solar wind and with extreme short-wave solar radiations. These problems are almost independent from those related to pictorial records (though not quite of the planet's albedo, color, and polarization). The Mercury-solar interactions will much depend on the strength of the planetary magnetic field, as yet unknown, but presumably small because of the planet's slow rotation. The corresponding lunar problems may again guide the Mercury studies rather than the immensely more complex phenomena associated with the Earth (summarized, e.g., by Friedman and Johnson 1970).

APPENDIX

Through the courtesy of Drs. E. C. Hubbard, C. Oesterwinter, and C. J. Cohen, we are able to reproduce in Fig. 5 two plots, showing the variation of the orbital eccentricity and inclination (with respect to the invariable plane of the solar system) for a period 10^7 years centered on the present. These plots are based on the theory by Brouwer and van Woerkom, "The Secular Variations of the Orbital Elements of the Principal Planets," *Astron. Papers,* Vol. XIII, Part II, 1950, and will be published with similar plots for the other planets in their new journal, *Celestial Mechanics.* They comment that Mercury's total variation of e, according to this plot, is from 0.239 to 0.110 as against 0.241 and 0.109, quoted in our text from Brouwer and Clemence.

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No. 144 THE ORBIT OF COMET BESTER 1946k-1947I

by G. VAN BIESBROECK

ABSTRACT

A discussion of the 118 measures of this comet, covering an interval of 700 days, led to a final near-parabolic orbit with a slight hyperbolic excess of eccentricity. However both original and future orbits turn out to be long-period ellipses.

This comet was found by M. J. Bester (1946) on a plate taken 1946 Oct. 31 at the Boyden Station, Bloemfontein (S.A.), with a 3-inch Ross-Fecker patrol camera. It appeared as an 11th magnitude round coma of 2′ diameter with a well-condensed nucleus.

It was immediately followed in many observatories. The brightness rose slowly. On December 19 a 20-minute exposure with the Yerkes 24-inch reflector showed a faint tail 6′ long in position angle 100°. By the middle of December, the brightness reached a maximum of 9th magnitude and slowly decreased after that. A great many measures were made from both sides of the equator in December 1946 and January 1947. As far south as Coelum, at discovery the comet moved north, crossing the equator on 1947 Feb 12, and then moved high in the northern hemisphere. It was lost in the evening sky after 1947 March 15 but was picked up again in the morning sky on June 23 when the brightness was reduced to 13th magnitude. Measures became scarce during the summer and fall 1947. By 1948 Jan 15 the comet had faded to 17th magnitude. After that there were only a couple of measures at the Lick Observatory on 1948 July 27 and two last measures on Oct 2 at the McDonald Observatory, when I estimated the magnitude as 18.5. The comet was then reduced to a very diffuse coma of 20″ diameter.

The observations were compared with L. E.

TABLE I

Residuals O - C

	UT	Δα	Δδ	Ob*
1946				
Nov.	2.92	$-0^{s}.42$	$+3''.4$	J
	3.89	-0.52	-0.5	J
	4.92	-0.60	-0.2	J
	5.02	-0.55	-0.8	C
	5.33	-0.23	-2.6	Y
	5.34	-0.46	-2.2	Y
	5.42	-0.44	+3.5	F
	5.44	-0.51	+1.1	L
	6.42	-0.60	-3.1	F
	7.00	-0.38	-1.7	L
	7.42	-0.41	-1.9	Y
	10.94	-0.65	-0.2	Y
Nov.	12.33	-0.42	+1.6	F
	13.90	-0.66	+1.7	Y
	15.11	-0.39	+2.1	S
	15.38	-0.83	+3.7	L
	15.41	-0.76	+2.7	L
	16.27	-0.88	+2.9	W
	17.84	-0.62	+2.6	Y
	18.04	-0.84	+3.1	S
	19.07	-0.50	+2.3	C
	19.24	-0.77	+1.5	Y
	20.05	-0.92	+4.0	S
	20.22	-0.83	+3.3	Y
Nov.	22.04	-0.78	+6.4	S
	23.08	-0.74	+6.5	S
	23.84	-0.34	+4.7	Y
	26.28	-0.49	+2.7	F
	27.03	-0.46	+4.7	C
	28.95	-0.34	+3.5	A
	29.04	-0.49	+3.5	S
	30.04	-0.28	+3.8	S
Dec.	1.06	-0.28	+3.5	S
	1.92	-0.54	+5.1	A
	2.93	-0.51	+4.8	A
	11.22	-0.67	+5.2	F
	11.74	-0.38	+5.3	Y
	12.14	-0.07	+8.9	S
	13.03	-0.39	+6.6	C
	14.15	-0.43	+5.7	W
	15.09	-0.28	+5.3	W
	15.10	-0.43	+6.3	W

	UT	Δα	Δδ	Ob
1946				
Dec.	15.79	$-0^{s}.38$	$+8''.3$	Y
	16.92	-0.34	+5.6	A
	19.10	-0.29	+6.0	Y
	19.14	-0.40	+6.6	W
	20.08	-0.30	+4.2	S
	20.19	-0.26	+5.7	L
	20.20	-0.23	+4.8	L
	21.90	-0.31	+5.5	A
	22.17	-0.36	+4.7	F
	23.76	-0.16	+4.2	Y
	23.32	-0.09	+5.3	A
	23.91	-0.06	+6.9	B
	26.81	-0.18	+7.0	B
	27.76	-0.32	+7.2	Y
	28.89	-0.23	+3.9	B
1947				
Jan.	4.76	-0.24	+1.0	Y
	8.76	-0.66	+5.3	Y
	10.05	-0.29	+6.1	C
	10.05	-0.20	+5.8	C
	11.00	-0.23	+3.0	Y
	11.08	-0.52	+3.7	S
	12.06	-0.50	+3.8	S
	12.76	-0.36	+6.4	Y
	14.73	-0.29	+4.9	V
	15.00	-0.26	+3.7	Y
	15.75	-0.14	+6.3	A
	15.77	-0.24	+5.6	A
	16.70	-0.13	+6.0	A
	18.02	-0.21	+2.7	Y
	18.06	-0.21	+5.2	C
	18.77	-0.22	+5.0	A
	18.78	-0.13	+4.2	A
	20.76	-0.30	+6.1	Y
	21.79	-0.27	+3.2	T
	23.02	-0.24	+5.9	Y
	23.05	-0.27	+2.8	L
	23.16	-0.26	+3.4	L
	23.75	-0.18	+5.2	Y
	29.75	-0.10	+5.1	Y
Feb.	11.03	-0.17	+4.3	Y
	12.10	-0.28	+6.6	F
	19.04	-0.16	+6.1	Y

	UT	Δα	Δδ	Ob
1947				
Feb.	19.79	$-0^{s}.27$	$+5''.6$	A
	19.80	-0.26	+4.1	A
	21.83	-0.20	+4.5	A
	22.71	-0.15	+2.5	A
	22.80	-0.22	+4.0	A
Mar.	11.80	-0.28	+5.1	A
	15.22	-0.10	+3.0	F
Jun.	23.11	-1.08	-19.5	A
July	20.09	-1.50	-27.1	A
	25.35	-1.20	-26.2	Y
Aug.	20.39	-1.33	-22.3	L
	20.40	-1.30	-21.8	L
Oct.	9.0	+11.21	-9.6	V
	17.92	+11.12	-9.8	A
	18.91	+10.92	-7.0	A
	18.98	+10.04	-8.5	A
Nov.	3.05	+10.20	+7.0	Y
	3.79	+10.18	+5.0	A
	4.20	+10.00	+6.8	L
	4.22	+10.11	+6.4	L
	8.25	+9.60	+5.8	L
	8.26	+9.61	+6.6	L
	8.78	+9.84	+6.6	A
	12.78	+9.76	+9.7	A
Dec.	8.77	+9.04	+16.4	A
	9.07	+9.00	+14.6	Y
1948				
Jan.	2.77	+8.50	+12.0	A
	2.81	+8.26	+17.2	A
July	27.22	+18.49	+31.8	L
	27.26	+18.50	+33.2	L
Oct.	2.13	+11.86	+91.7	M
	2.16	+11.78	+91.6	M

* Observatories and Observers:

A Algiers - Boyer & Schmidt
B Barcelona - Fabre
C Cordoba - Bobone
F Flagstaff - Giclas
J Johannesburg - Johnson
L Lick - Jeffers
M McDonald - Van Biesbroeck
S Santiago - Dujisin
T Toulouse - Prêtre
V Vienna - Krumpholtz
W Washington - Reuning
Y Yerkes - Van Biesbroeck

Cunningham's parabolic orbit:

$$\left.\begin{array}{l} T = 1947 \text{ Feb } 7.4216 \text{ U.T.} \\ \omega = 348^\circ\!.64149 \\ \Omega = 34.86152 \\ i = 108.16837 \\ q = 2.407373 \end{array}\right.$$

(ω, Ω, i: 1950)

Table I gives the list of residuals for the 108 observations that were retained after omitting a few that were obviously in error.

The residuals were grouped in 15 normal places listed in Table II.

Perturbations were computed by Encke's method in 4-day intervals, the comet remaining far from all planets. Mercury and Pluto were omitted in this computation. 1947 Oct 2 was adopted as osculation date, about midway of the 699 days covered by the measures. Because of the large perihelion distance, the true anomaly varied only from −33° to +70° over these nearly two years.

The coefficients of the equations of condition were computed in the form given by Stracke (1929). For that purpose the ecliptic elements were transformed into equatorial ones:

$$\left.\begin{array}{lll} \omega' = & 5^\circ\ 5' & 54''\!.8 \\ \Omega' = & 42\ \ 34 & 18.8 \\ i' = & 126\ \ 36 & 12.5 \end{array}\right\}\ 1950$$

The equations of condition were solved on the 7071 IBM computer of the University of Arizona. The corrections of the equatorial elements and their probable errors are as follows:

$$\begin{aligned} de &= +0.0005888 \pm 0.0000755 \\ dq &= +0.0001550 \pm 0.0000139 \\ dT &= -0.09370 \quad \pm 0.00022 \end{aligned}$$

$$\begin{aligned} d\omega' &= -1'\ 59''\!.82 \pm 0''\!.25 \\ d\Omega' &= -0\ \ 14.05 \pm 0.09 \\ di' &= +0\ \ \ 3.67 \pm 0.12 \end{aligned}$$

The final elements become:

T 1947 Feb 7.32790 U.T.
q 2.407528
e 1.0005888

	Equator			Ecliptic			
ω	5°	3′	54″98	348°	36′	33″9	1950.0
Ω'	42	34	4.75	34	51	28.3	
i	126	36	16.17	108	10	8.5	

Osculation date 1947 Oct 2.0. Since the eccentric excess is 8 times larger than its probable error, the hyperbolic character of the solution is firmly established.

It is of interest to find out what was the nature of the original orbit and what it will become in the

TABLE II

Normal Places

UT			Weight	Perturbations		To be Corrected		Final Residuals	
	$\Delta\alpha\cos\delta$	$\Delta\delta$		$\Delta\alpha\cos\delta$	$\Delta\delta$	$\Delta\alpha\cos\delta$	$\Delta\delta$	$\Delta\alpha\cos\delta$	$\Delta\delta$
1946 Nov 6	− 3″.8	− 0″.4	12	− 6″.4	+21″.0	+ 2″.6	−21″.4	+0″.5	+1″.0
Nov 18	− 7.0	+ 2.6	12	− 0.5	+19.7	− 6.5	−17.7	−1.8	−1.4
Nov 27	− 5.5	+ 4.5	11	+ 3.0	+17.8	− 8.5	−13.3	+0.9	−0.8
Dec 19	− 4.0	+ 5.9	22	+10.0	+ 8.2	− 14.0	− 2.3	+1.1	+2.2
1947 Jan 16	− 4.2	+ 4.7	22	+ 9.8	+ 4.4	− 14.0	+ 0.3	−1.3	−2.1
Feb 19	− 3.7	+ 4.7	8	+ 6.2	+ 0.5	− 9.9	+ 4.0	+0.2	−1.1
Mar 13	− 2.3	+ 4.0	2	+ 4.8	− 0.6	− 7.5	+ 4.6	+1.7	−0.7
June 23	− 12.3	+19.5	1	+ 1.0	− 0.9	− 13.3	−20.4	+1.5	−3.2
July 23	− 12.1	−26.7	2	+ 0.8	− 0.6	− 12.9	−26.1	−2.7	+2.8
Oct 18	+ 94.6	− 8.7	4	+ 0.1	0.0	+ 94.5	− 8.7	+0.5	−0.7
Nov 7	+ 94.6	+ 7.1	4	+ 0.2	+ 0.1	+ 94.4	+ 7.0	−1.4	+2.9
Dec 9	+ 96.6	+15.5	2	+ 0.5	+ 0.3	+ 96.1	+15.2	+3.3	−2.6
1948 Jan 3	+ 93.8	+14.6	2	+ 0.9	+ 0.5	+ 92.9	+14.1	0.0	+1.3
July 27	+ 99.4	+32.5	2	+ 2.8	+ 7.4	+ 96.6	+25.1	−1.6	+3.1
Oct 2	+116.7	+91.6	2	+ 0.8	+ 8.7	+117.5	+82.9	+1.9	−1.0

future. Dr. B. G. Marsden of the Smithsonian Astrophysical Observatory in Cambridge (Mass.) kindly offered to compute the effect of all the planets on the reciprocal value of the semi-major axis. This was done on the IBM 7094 computer of the Harvard University, using an integration program written by J. Schubart and P. Stumff of Heidelberg.

The final values of $1/a$ come out as follows:

Osculating value 1947 October 2	− 0.0002446
Perturbations 1947–1920	+ 0.0004755
Reduction to barycenter	− 0.0001342
Original value at 48 a.u. 1920 April 26	+ 0.0000967
Osculating value 1947 October 2	− 0.0002446
Perturbations 1947–1975	+ 0.0003928
Reduction to barycenter	+ − 0.0000242
Future value at 50 a.u. 1975 March 9	+ 0.0001240

Both the original and future orbits therefore become clearly elliptical, but the period is of the order of a million years.

Note. After this work was completed E. Roemer called my attention to the fact that I had omitted the observations 1947 Jan 23 to 1948 May 11 in L.O.B. 520. The corresponding residuals in Table I are:

1947	Jan 23.15	− 0^s.34	+ 4$''$.3	L
	23.16	− 0.34	+ 4.2	L
	Aug 20.39	− 1.28	−22.4	L
	20.40	− 1.26	−22.6	L
	Nov 4.21	+10.0	+ 6.2	L
	4.22	+10.02	+ 6.6	L

Since they fall within the ones that I used, their inclusion would hardly have changed the normal places. Hence a new solution was not attempted.

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No. 145 MEASURES OF THE SATELLITES OF URANUS AND MARS

by G. VAN BIESBROECK

ABSTRACT

Relative measures are made of the satellites of Uranus and Mars, from plates taken with the 82-inch McDonald Observatory reflector telescope, and the 61-inch NASA telescope at the Catalina Observatory.

82-Inch Reflector

When the writer joined the Lunar and Planetary Laboratory at the University of Arizona, he found available there a considerable number of unmeasured plates of the Uranus system taken with the 82-inch reflector of the McDonald Observatory. The most extensive series was obtained after the discovery of the fifth satellite in 1948 by Dr. G. P. Kuiper by him and D. L. Harris. Shorter series were added by Kuiper in 1954, 1960 and 1961, and by the writer in 1962 and 1964.

On all the plates, the image of the planet was so overexposed that it was not possible to refer the satellites to the planet's center. Only intercomparisons of the satellites could be made. For that purpose the plates were measured in rectangular coordinates on the comparator of the Steward Observatory, using the *Astrographic Catalogue* as the source of the reference star coordinates. The deduced positions, reduced to the equinox of 1950.0, are affected by the uncertainty of the plate constants of the *Astrographic Catalogue* but since only differences in position are used, these uncertainties enter only as a second-order effect and are therefore completely negligible.

The observation times are given in decimal fractions of UT days. The satellites are designated by the initials M (Miranda), A (Ariel), U (Umbriel), T (Titania), and O (Oberon).

The equatorial coordinates of the brightest satellite, Titania, are given for the epoch 1950.0. They are followed by the differences satellite minus Titania in x and y.

Measures of low weight are designated according to the following schedule:

(1) Image faint
(2) image very faint
(3) all images poor
(4) image affected by diffraction rays
(5) image close to the planet

OBSERVATIONS AT 82-INCH REFLECTOR, McDONALD OBSERVATORY

1948 Mar 1.10943

T	$5^h\ 25^m47^s.12$	$+23^\circ\ 22'\ 13''.0$
M	$-23''.32$	$+1''.15$
A	−44.06	+13.11
U	−12.55	+ 3.49
O	−54.34	−31.15

1948 Mar 1.11499

T	5 25 47.13	+23 22 13.1
M	−22.52	+ 1.45
A	−44.24	+12.95
U	−12.58	+ 3.56
O	−54.64	−31.30

1948 Oct 19.41542

T	6 2 15.93	+23 37 45.5
A	+ 4.16	+21.13
U	+35.59	+31.34
O	+53.17	+ 3.20

1948 Oct 19.41875

T	6 2 15.98	+23 37 45.5
A	+ 4.06	+21.22
O	+52.96	+ 3.17

1948 Oct 21.45142

T	6 2 12.37	+23 37 54.0
A	−33.78	+31.40
U	−43.00	+17.28
O	+14.20	+36.15

1948 Oct 21.45498

T	6 2 12.38	+23 37 53.8
A(2)	−33.83	+31.36
U	−43.38	+17.53
O	+14.40	+36.01

1948 Oct 24.35066(3)

T	6 2 0.05	+23 38 51.3
M(1)	− 2.74	−40.59
A	−18.52	−32.92
U	− 3.02	−12.09
O	−12.87	+10.96

1948 Oct 24.47990

T	6 1 59.27	+23 38 51.5
M(1)	−12.50	−38.90
A	−14.26	−37.64
U	− 3.82	−12.40
O	−12 31	+10.07

1948 Oct 24.48939

T	6 1 59.21	+23 38 51.4
A	−13.82	−37.88
U	− 3.86	−12.99
O	−12.16	+10.19

1948 Oct 24.49390

T	6 1 59.24	+23 38 51.4
A	−13.82	−38.39
U	− 3.94	−12.64
O	−12.33	+10.05

1948 Oct 24.50003

T	6 1 59.16	+23 38 51.4
A	−13.58	−38.33
U	− 4.00	−12.50
O	−12.28	+10.03

1948 Oct 25.35384

T	6 1 54.26	+23 38 47.6
M(2)	+ 7.58	−26.84
A	+29.32	−34.76
U	− 1.97	−24.16
O	− 8.72	+ 7.46

1948 Oct 25.36771

T	6 1 54.17	+23 38 47.5
M	+ 8.14	−27.20
A	+29.75	−34.22
U	− 1.63	−24.41
O	− 8.66	+ 7.47

1948 Oct 25.37250(3)

T	$6^h\ 1^m54^s.14$	$+23^\circ\ 38'\ 47''.5$
M	$+8''.15$	$-27''.43$
A	+29.89	−34.06
U	− 1.67	−24.47
O	− 8.71	+ 7.41

1948 Oct 25.37940

T	1 54.10	+23 38 47.4
M(2)	+ 8.9	−27.58
A	+30.08	−33.73
U	− 1.58	−24.67
O	− 8.70	+ 7.45

1948 Oct 25.38338

T	6 1 54.07	+23 38 47.3
M	+ 8.45	−27.92
A	+30.25	−33.63
U	− 1.43	−24.74
O	− 8.61	+ 7.37

1948 Oct 25.42210

T	6 1 53.84	+23 38 47.0
M(2)	+ 9.57	−28.99
A	+31.60	−31.88
U	− 0.73	−25.43
O	− 8.60	+ 7.44

1948 Oct 25.42671

T	6 1 53.82	+23 38 46.8
M	+ 9.55	−29.12
A	+31.68	−31.65
U	− 0.74	−25.40
O	− 8.49	+ 7.51

1948 Oct 25.43311

T	6 1 53.78	+23 38 46.7
M	+ 9.72	−29.25
A	+31.84	−31.37
U	− 0.50	−25.47
O	− 8.47	+ 7.52

1948 Oct 25.43786

T	6 1 53.76	+23 38 46.8
M(2)	+ 9.91	−29.43
A	+31.91	−31.12
U	− 0.18	−25.66
O	− 8.49	+ 7.47

1948 Oct 25.46947

T	6 1 53.58	+23 38 46.3
M	+10.94	−30.31
A	+32.78	−29.68
U	+ 0.12	−26.22
O	− 8.36	+ 7.49

1948 Oct 25.47377

T	6 1 53.55	+23 38 46.3
A	+33.05	−29.44
U	+ 0.15	−25.96
O	− 8.32	+ 7.46

1948 Oct 25.48518

T	6 1 53.49	+23 48 46.1
M	+11.50	−30.62
A	+33.22	−28.89
U	+ 0.33	−26.44
O	− 8.28	+ 7.54

1948 Oct 25.48866

T	6 1 53.47	+23 48 46.0
M(4)	+11.84	−30.67
A	+33.33	−28.72
U	+ 0.39	−26.49
O	− 8.30	+ 7.63

1948 Oct 26.35302(3)

T	6 1 48.30	+23 38 31.1
A	+25.12	+ 3.31
U	+27.07	−28.91
O	− 7.81	+10.26

1948 Oct 26.35918(3)

T	$6^h\ 1^m48^s.27$	$+23^\circ\ 38'\ 31''.0$
A	$+24''.92$	$+3''.36$
U	+27.31	−28.82
O	− 7.70	+10.27

1948 Oct 26.36479

T	6 1 48.23	+23 38 30.9
A	+24.81	+ 3.43
U	+27.56	−28.75
O	− 7.83	+10.32

1948 Oct 26.42062

T	6 1 47.96	+23 38 29.7
M	+31.10	+ 1.08
A	+23.24	+ 3.67
U	+29.33	−27.84
O	− 7.93	+10.51

1948 Oct 26.42514

T	6 1 47.92	+23 38 29.6
M	+30.70	+ 1.45
A	+23.00	+ 3.76
U	+29.18	−27.64
O	− 7.82	+10.57

1948 Oct 26.43583

T	6 1 47.85	+23 38 29.4
A	+22.94	+ 3.77
U	+30.01	−27.43
O	− 8.02	+10.57

1948 Oct 26.43863

T	6 1 47.86	+23 38 29.4
A	+22.87	+ 3.80
U	+29.90	−27.43
O	− 8.00	+10.63

1948 Oct 26.47898

T	6 1 47.63	+23 39 28.4
A	+21.96	+ 3.88
U	+31.18	−26.58
O	− 8.12	+10.87

1948 Oct 26.48178

T	6 1 47.63	+23 38 28.4
A	+22.00	+ 3.81
U	+31.31	−26.47
O	− 8.02	+10.78

1948 Oct 26.48634

T	6 1 47.61	+23 38 28.3
M	+28.46	+ 2.21
A	+21.91	+ 3.87
U	+31.50	−26.47
O	− 8.12	+10.81

1948 Oct 26.49135

T	6 1 47.58	+23 38 28.2
M	+28.42	+ 2.33
A	+21.74	+ 3.92
U	+31.84	−26.33
O	− 8.07	+10.78

1948 Oct 26.49633

T	6 1 47.51	+23 38 28.0
M	+28.65	+ 2.63
A	+21.57	+ 3.82
U	+31.86	−26.14
O	− 8.22	+10.90

1948 Oct 27.31338

T	6 1 44.58	+23 38 10.5
A	+24.44	− 1.03
U	+47.38	+ 5.75
O	−13.61	+13.60

1948 Oct 27.32473

T	6 1 44.53	+23 38 10.3
A	+24.62	− 0.95
U	+47.38	+ 6.22
O	−13.64	+13.69

OBSERVATIONS AT 82-INCH REFLECTOR, McDONALD OBSERVATORY

1948 Oct 27.33064

T	6^h $1^m44^s.51$	$+23^\circ$ 38' 10".2
A	+24".80	− 0".94
U	+47.31	+ 6.38
O	−13.67	+13.63

1948 Oct 27.34237

T	6 1 44.45	+23 38 10.0
A	+25.13	− 0.73
U	+47.39	+ 7.06
O	−13.79	+13.63

1948 Oct 27.35640

T	6 1 44.39	+23 38 9.7
A	+25.37	− 0.55
U	+47.29	+ 7.78
O	−13.80	+13.76

1948 Oct 27.36730

T	6 1 44.30	+23 38 9.5
A	+25.74	− 0.56
U	+47.34	+ 7.91
O	−13.99	+13.78

1948 Oct 27.37537

T	6 1 44.30	+23 38 9.4
A	+25.87	− 0.36
U	+47.36	+ 8.71
O	−14.06	+13.74

1948 Oct 27.38366

T	6 1 44.26	+23 38 9.1
A	+26.20	− 0.18
U	+47.33	+ 9.38
O	−14.26	+13.73

1948 Oct 27.39648

T	6 1 44.23	+23 38 8.9
M(2)	+35.90	+ 8.73
A	+26.44	− 0.06
A	+47.20	+ 9.74
O	−14.29	+13.72

1948 Oct 27.40045

T	6 1 44.21	+23 38 8.7
A	+26.56	− 0.02
U	+47.22	+ 9.99
O	−14.39	+13.85

1948 Oct 27.40370

T	6 1 44.19	+23 38 8.8
A	+26.57	− 0.02
U	+47.09	+10.08
O	−14.36	+13.72

1948 Oct 27.40816

T	6 1 44.20	+23 38 8.7
M(2)	+37.04	+ 9.07
A	+26.64	− 0.04
U	+47.16	+10.07
O	−14.49	+13.73

1948 Oct 27.46433(3)

T	6 1 43.96	+23 38 7.7
A	+27.96	+ 1.25
U	+46.70	+13.28
O	−15.06	+13.75

1948 Oct 27.46916(3)

T	6 1 43.92	+23 38 7.6
M(2)	+36.64	+14.56
A	+28.11	+ 1.32
U	+46.66	+13.41
O	−14.99	+13.71

1948 Oct 27.47368(3)

T	6 1 43.90	+23 38 7.5
M	+36.67	+14.96
A	+28.24	+ 1.43
U	+46.56	+13.68
O	−15.10	+13.80

1948 Oct 27.47757

T	6^h $1^m43^s.88$	$+23^\circ$ 38' 7".4
A	+28".38	+ 1".58
U	+46.63	+13.85
O	−15.11	+13.87

1948 Oct 27.48733(3)

T	6 1 43.87	+23 38 7.0
M	+36.43	+15.84
A	+28.49	+ 1.74
U	+46.45	+14.23
O	−15.20	+13.79

1948 Oct 27.49157

T	6 1 43.85	+23 38 6.9
A	+28.68	+ 1.84
U	+46.45	+14.53
O	−15.25	+13.82

1948 Oct 31.40562

T	6 1 27.86	+23 38 34.5
M	−29.45	−15.70
A	−37.05	+ 6.74
U	−12.86	−14.05
O	−16.76	−47.42

1948 Oct 31.41123

T	6 1 27.83	+23 38 34.7
M	−28.69	−15.68
A	−37.21	+ 6.50
U	−12.90	−14.12
O	−16.70	−47.41

1948 Oct 31.41677

T	6 1 27.79	+23 38 34.9
M	−28.83	−15.75
A	−37.36	+ 6.16
U	−12.82	−14.14
O	−16.53	−47.69

1948 Oct 31.42326

T	6 1 27.76	+23 38 35.1
M	−28.66	−15.89
A	−37.48	+ 5.94
U	−12.71	−14.14
O	−16.44	−47.76

1948 Oct 31.42938

T	6 1 27.80	+23 38 35.2
M	−28.55	−16.16
A	−37.58	+ 5.75
U	−12.79	−14.17
O	−16.38	−47.83

1948 Oct 31.43535

T	6 1 27.68	+23 38 36.0
M	−28.13	−15.98
A	−37.76	+ 5.46
U	−12.49	−14.03
O	−15.98	−47.17

1948 Oct 31.44056

T	6 1 27.65	+23 38 35.6
M	−27.85	−16.33
A	−37.79	+ 5.55
U	−12.37	−14.15
O	−15.84	−48.34

1948 Oct 31.44682

T	6 1 27.62	+23 38 35.6
M	−27.58	−16.28
A	−38.14	+ 4.99
U	−12.39	−14.01
O	−15.78	−48.10

1948 Oct 31.45894

T	6 1 27.53	+23 38 35.9
M	−27.04	−16.42
A.	−38.35	+ 4.77
U	−12.07	−13.96
O	−15.47	−48.29

1948 Oct 31.46479

T	6^h $1^m27^s.50$	$+23^\circ$ 38' 36".0
M(2)	−27".01	−16".42
A	−38.43	+ 4.40
U	−12.12	−13.79
O	−15.35	−48.20

1948 Oct 31.47044

T	6 1 27.46	+23 38 36.1
M(2)	−26.65	−16.58
A	−38.65	+ 4.18
U	−11.91	−13.91
O	−15.08	−48.45

1948 Oct 31.47597

T	6 1 27.39	+23 38 36.5
M(2)	−26.11	−16.70
A	−38.88	+ 3.58
U	−11.69	−13.85
O	−14.71	−49.00

1948 Oct 31.48150

T	6 1 27.39	+23 38 36.4
M(2)	−25.76	−16.79
A	−38.95	+ 4.30
U	−11.87	−13.87
O	−14.81	−48.71

1948 Oct 31.48692

T	6 1 27.48	+23 38 36.3
M(1)	−26.29	−16.73
A	−38.48	+ 3.83
U	−11.71	−13.91
O	−14.98	−48.62

1948 Nov 6.33889

T	6 0 48.68	+23 38 3.4
M(2)	+15.83	+29.89
A	+ 0.02	+19.22
U	− 7.03	+46.65
O	+ 7.72	+75.34

1948 Nov 6.34444

T	6 0 48.65	+23 38 3.4
M(1)	+15.26	+30.53
A	+ 0.01	+18.97
U(4)	− 7.21	+46.40
O	+ 7.49	+75.28

1948 Nov 6.35000

T	6 0 48.63	+23 38 3.3
M(1)	+15.80	+30.76
A	− 0.05	+19.16
U(4)	− 7.46	+46.69
O	+ 7.28	+75.32

1948 Nov 6.35556(3)

T	6 0 48.58	+23 38 3.5
M(1)	+15.56	+30.77
A	− 0.05	+18.96
U	− 7.78	+46.38
O	+ 7.28	+75.21

1948 Nov 6.36875

T	6 0 48.53	+23 38 3.3
M(1)	+14.71	+31.42
A	− 0.04	+18.95
O	+ 6.51	+75.39

1948 Nov 6.37431

T	6 0 48.50	+23 38 3.5
M(1)	+14.56	+31.67
A	− 0.12	+18.70
O	+ 6.29	+75.42

1948 Nov 6.38056

T	6 0 48.46	+23 38 3.3
M(1)	+15.02	+31.81
A	+ 0.05	+18.78
O	+ 6.07	+75.47

OBSERVATIONS AT 82-INCH REFLECTOR, MCDONALD OBSERVATORY

1948 Nov 6.38681

T	6^h $0^m48^s.43$	$+23^\circ$ 38'	3".3
M(1)	+14".69	+31".91	
A	+ 0.18	+18.71	
O	+ 6.38	+75.44	

1948 Nov 6.40208

T	6 0 48.36	+23 38	3.4
M	+14.41	+32.73	
A	+ 0.47	+18.32	
O	+ 4.97	+75.54	

1948 Nov 6.40903

T	6 0 48.33	+23 38	3.5
M	+14.27	+32.92	
A	+ 0.66	+18.41	
O	+ 4.65	+75.40	

1948 Nov 6.41458

T	6 0 48.30	+23 38	3.4
M(1)	+13.99	+33.20	
A	+ 0.64	+18.28	
O	+ 4.43	+75.46	

1948 Nov 6.42014

T	6 0 48.27	+23 38	3.4
A	+ 0.76	+18.49	
O	+ 4.18	+75.54	

1948 Nov 6.44028

T	6 0 48.17	+23 38	3.3
M(1)	+12.94	+34.46	
A	+ 1.04	+18.38	
U(4)	-11.30	+44.76	
O	+ 3.44	+75.70	

1948 Nov 6.44583

T	6 0 48.14	+23 38	3.3
A	+ 1.10	+18.28	
U	-11.34	+44.75	
O	+ 3.08	+75.70	

1948 Nov 6.45208

T	6 0 48.10	+23 38	3.1
A	+ 1.11	+18.29	
U	-11.74	+44.61	
O	+ 2.95	+75.74	

1948 Nov 6.45764

T	6 0 48.08	+23 38	3.1
A	+ 1.21	+18.37	
U	-12.01	+44.67	
O	+ 2.62	+75.79	

1948 Nov 6.46319

T	6 0 48.05	+23 38	3.1
M	+12.41	+35.18	
A	+ 1.31	+18.15	
U	-12.48	+44.38	
O	+ 2.21	+75.81	

1948 Nov 6.46875

T	6 0 48.02	+23 38	3.2
A	+ 1.17	+18.37	
U	-12.15	+44.47	
O	+ 2.27	+75.82	

1948 Nov 7.35694

T	6 0 43.39	+23 38	7.8
M	-19.46	+19.72	
A	- 4.13	+34.85	
U	-30.80	+15.85	
O	-34.82	+68.48	

1948 Nov 7.36181

T	6 0 43.35	+23 38	7.9
M	-19.77	+19.46	
A	- 4.17	+35.00	
U	-30.80	+15.72	
O	-34.93	+68.47	

1948 Nov 7.36667

T	6^h $0^m43^s.32$	$+23^\circ$ 38'	8".1
M	-19".51	+19".49	
A	- 4.46	+35.05	
U	-30.82	+15.51	
O	-35.05	+68.38	

1948 Nov 8.39444(3)

T	6 0 37.12	+23 38	27.8
A	-44.50	+11.56	
U	-17.45	- 4.85	
O	-64.57	+37.60	

1948 Nov 8.39931

T	6 0 37.08	+23 38	28.0
A	-44.53	+11.26	
U	-17.49	- 4.85	
O	-64.55	+37.42	

1948 Nov 8.40417

T	6 0 37.06	+23 38	28.0
A	-44.67	+10.87	
U	-17.53	- 4.83	
O	-64.84	+37.21	

1948 Nov 8.40903

T	6 0 37.02	+23 38	28.2
A	-44.47	+10.64	
U	-17.45	- 4.91	
O	-64.80	+36.94	

1948 Nov 8.41875

T	6 0 36.95	+23 38	28.4
A	-44.63	+ 9.98	
U	-17.26	- 4.84	
O	-64.98	+36.53	

1948 Nov 8.42361

T	6 0 36.92	+23 38	28.5
A	-44.61	+ 9.96	
U	-16.93	- 4.93	
O	-65.02	+36.53	

1948 Nov 8.42847

T	6 0 36.88	+23 38	28.6
A	-44.60	+ 9.60	
U	-17.06	- 4.72	
O	-65.05	+36.55	

1948 Nov 10.31667

T	6 0 22.00	+23 39	8.7
A	-14.85	-14.28	
U	-23.75	-10.75	
O	-56.06	-37.93	

1948 Nov 10.32153

T	6 0 21.96	+23 39	8.9
A	-14.86	-14.23	
U	-23.96	-10.75	
O	-55.90	-37.96	

1948 Nov 10.32639

T	6 0 21.92	+23 39	8.8
A	-15.11	-14.09	
U	-24.09	-10.89	
O	-55.98	-37.89	

1948 Nov 10.33125

T	6 0 21.87	+23 39	9.0
A	-15.21	-14.42	
U	-24.04	-11.08	
O	-55.76	-38.24	

1948 Nov 10.33611

T	6 0 21.82	+23 39	8.9
A	-15.18	-14.41	
U	-24.08	-11.12	
O	-55.55	-38.24	

1948 Nov 10.34097

T	6^h $0^m21^s.77$	$+23^\circ$ 39'	9".2
A	-15.25	-14".55	
U	-23.99	-11.56	
O	-55.50	-38.56	

1948 Nov 10 34583

T	6 0 21.74	+23 39	9.1
A	-15.57	-14.55	
U	-24.09	-11.41	
O	-55.41	-38.63	

1948 Nov 10.35069

T	6 0 21.69	+23 39	9.0
A	-15.22	-14.60	
U	-23.91	-11.45	
O	-55.13	-38.72	

1948 Nov 10.37500

T	6 0 21.56	+23 39	9.6
A	-15.53	-14.95	
U(4)	-24.19	-12.02	
O	-54.95	-39.47	

1948 Nov 10.37986

T	6 0 21.43	+23 39	9.6
A	-15.88	-14.94	
U(4)	-23.17	-12.13	
O	-54.69	-39.64	

1948 Nov 10.38472

T	6 0 21.36	+23 39	9.8
A	-15.68	-15.22	
U(4)	-24.04	-12.59	
O	-54.25	-39.91	

1948 Nov 10.38981

T	6 0 21.32	+23 39	9.8
A	-15.25	-15.14	
U(4)	-24.26	-12.66	
O	-54.19	-40.01	

1948 Nov 10.39653

T	6 0 21.25	+23 39	9.9
A	-15.85	-15.35	
U(4)	-24.24	-12.79	
O	-53.99	-40.27	

1948 Nov 10.40139

T	6 0 21.22	+23 39	9.9
A	-16.24	-15.32	
U(4)	-24.48	-12.80	
O	-53.93	-40.27	

1948 Nov 10.40625

T	6 0 21.17	+23 39	10.0
A	-16.11	-15.43	
U	-24.33	-12.85	
O	-53.78	-40.49	

1948 Nov 10.41111

T	6 0 21.13	+23 39	10.1
A	-16.22	-15.50	
U	-24.30	-13.03	
O	-53.68	-40.57	

1948 Nov 10.42014

T	6 0 21.06	+23 39	10.2
A	-16.21	-15.67	
O	-53.45	-40.97	

1948 Nov 10.42500

T	6 0 21.01	+23 39	10.2
A	-16.57	-15.78	
O	-53.37	-41.07	

1948 Nov 10.43056

T	6 0 20.95	+23 39	10.2
A	-16.40	-15.94	
O	-53.18	-41.18	

OBSERVATIONS AT 82-INCH REFLECTOR, McDONALD OBSERVATORY

1948 Nov 10.43623

T	6h 0m20s.90	+23° 39' 10".4
A	-16".56	-16".07
O	-53.09	-41.27

1948 Nov 11.36389

T	6 0 12.38	+23 39 13.2
A	+ 2.16	-44.00
U	- 8.09	-41.03
O	-22.69	-60.14

1948 Nov 11.36773

T	6 0 12.33	+23 39 13.2
A	+ 2.44	-44.14
U	- 7.82	-40.94
O	-22.45	-59.99

1949 Feb 24.07847

T	5 44 56.70	+23 37 13.4
A	+17.29	-15.13
U(1)	+26.30	-44.45
O	-19.73	- 2.49

1949 Feb 24.08405

T	5 44 56.61	+23 37 13.4
A	+17.26	-15.11
U	+26.61	-44.41
O	-19.73	- 2.73

1949 Feb 24.08924

T	5 44 56.67	+23 37 13.3
A	+17.15	-14.90
U	+26.82	-44.18
O	-19.60	- 2.53

1949 Feb 24.09931

T	5 44 56.62	+23 37 13.1
A	+16.87	-14.72
U	+27.43	-43.86
O	-18.94	- 2.62

1949 Feb 24.16045

T	5 44 56.39	+23 37 12.4
M	+11.29	-35.12
A	+16.24	-13.86
U	+29.89	-42.00
O	-18.99	- 2.95

1949 Feb 24.16667

T	5 44 56.37	+23 37 12.4
M(5)	+11.69	-35.89
A	+16.01	-13.83
U	+30.01	-41.78
O	-19.00	- 3.04

1949 Feb 27.10118

T	5 44 51.40	+23 36 14.6
A	+ 2.62	+35.17
U	- 2.15	+18.74
O	-16.13	- 1.13

1949 Feb 27.11159

T	5 44 51.40	+23 36 14.6
M(5)	+14.93	+18.58
A	+ 2.22	+34.76
U	- 2.19	+18.42
O	-15.84	- 1.27

1949 Feb 27.11691

T	5 44 51.40	+23 36 14.5
M	+14.97	+18.71
A	+ 2.02	+34.73
U	- 2.21	+18.56
O	-15.94	- 1.22

1949 Feb 27.15733

T	5 44 51.38	+23 36 14.0
M(1)	+16.10	+19.61
A	+ 0.72	+33.91
U	- 2.16	+17.82
O	-16.09	- 1.37

1949 Feb 27.16126

T	5h 44m51s.39	+23° 36' 14".0
M(5)	+15".70	+19".43
A	+ 0.52	+33.79
U	- 2.39	+17.68
O	-16.16	- 1.37

1949 Feb 27.16682

T	5 44 51.39	+23 36 13.9
M(5)	+16.01	+19.71
A	+ 0.23	+33.76
U	- 2.46	+17.81
O	-16.19	- 1.33

1949 Feb 27.17203

T	5 44 51.39	+23 36 13.9
A	+ 0.01	+33.64
U	- 2.58	+17.54
O	-16.30	- 1.47

1954 Jan 29.28264

T	7 27 59.12	+22 24 42.5
A	-36.23	-12.75
U	-21.92	+ 3.67
O	+ 7.62	+ 6.82

1954 Jan 29.28472

T	7 27 59.09	+22 24 42.5
A	-36.08	-12.77
U	-21.69	+ 3.65
O	+ 7.65	+ 6.80

1954 Jan 29.29167

T	7 27 59.01	+22 24 42.8
M	-22.40	- 7.45
A	-36.13	-13.22
U	-21.90	+ 3.62
O	+ 7.55	+ 6.86

1954 Jan 29.29757

T	7 27 58.94	+22 24 43.0
M(1)	-22.28	- 7.10
A	-36.01	-13.60
U	-21.78	+ 3.48
O	+ 7.71	+ 6.82

1960 Apr 15.14141

T	9 17 59.76	+16 28 55.9
A	+18.01	+28.87
U	+ 7.50	+20.23
O	- 6.28	+ 7.03

1960 Apr 15.14433

T	9 17 59.76	+16 28 55.9
A	+17.74	+29.02
U	+ 7.28	+20.28
O	- 6.45	+ 7.12

1960 Apr 15.14867

T	9 17 59.75	+16 28 55.9
A	+17.56	+29.20
U	+ 7.28	+20.27
O	- 5.96	+ 7.14

1960 Apr 15.15284

T	9 17 59.74	+16 28 55.7
A	+17.57	+29.19
U	+ 7.37	+20.20
O	- 6.35	+ 7.01

1960 Apr 15.18322

T	9 17 59.69	+16 28 55.1
M	+12.13	+ 7.11
A	+16.87	+29.68
U	+ 6.98	+19.98
O	- 6.48	+ 7.24

1960 Apr 15.18582

T	9 17 59.64	+16 28 55.2
M	+12.36	+ 7.13
A	+16.90	+29.65
U	+ 7.01	+20.08
O	- 6.52	+ 7.42

1950 Apr 15.20581

T	9h 17m59s.62	+16° 28' 55".1
M	+12".62	+ 7".63
A	+16.42	+30.18
U	+ 6.76	+19.76
O	- 6.50	+ 7.19

1960 Apr 15.20961

T	9 17 59.62	+16 28 54.9
M	+12.54	+ 7.12
A	+16.30	+30.15
U	+ 6.73	+19.82
O	- 6.56	+ 7.20

1960 Apr 15.25777

T	9 17 59.54	+16 28 54.2
M	+13.23	+ 6.24
A	+15.25	+30.91
U	+ 6.28	+19.47
O	- 6.85	+ 7.81

1960 Apr 16.09625

T	9 17 58.42	+16 28 46.4
M	+ 9.80	+39.13
A	+ 4.08	+19.52
U	+ 4.19	+11.57
O	-10.88	+ 4.74

1960 Apr 16.09972

T	9 17 58.42	+16 28 46.3
M	+ 9.70	+39.28
A	+ 3.92	+19.36
U	+ 3.98	+11.72
O	-11.07	+ 4.75

1960 Apr 16.10627

T	9 17 58.41	+16 28 46.3
M	+ 9.62	+39.30
A	+ 4.12	+19.30
U	+ 4.15	+11.98
O	-10.83	+ 4.67

1960 Apr 16.12123

T	9 17 58.40	+16 28 46.3
M	+ 9.10	+39.09
A	+ 3.96	+19.00
U	+ 4.11	+11.62
O	-11.13	+ 4.59

1960 Apr 16.13097

T	9 17 58.38	+16 28 46.3
M	+ 8.84	+39.08
A	+ 4.03	+18.96
U	+ 4.33	+11.41
O	-11.18	+ 4.50

1960 Apr 16.13444

T	9 17 58.38	+16 28 46 3
M	+ 8.57	+38.94
A	+ 4.15	+18.86
U	+ 4.30	+11.53
O	-11.11	+ 4.44

1960 Apr 16.17542

T	9 17 58.32	+16 28 46.2
M	+ 7.44	+38.48
A	+ 4.27	+18.52
U	+ 4.47	+11.50
O	-11.52	+ 4.04

1960 Apr 16.17858

T	9 17 58.33	+16 28 46.2
A	+ 4.10	+18.41
U	+ 4.36	+11.56
O	-11.51	+ 4.11

1960 Apr 16.21535

T	9 17 58.28	+16 28 46.1
A	+ 4.36	+18.05
U	+ 4.58	+11.63
O	-11.70	+ 3.72

Observations at 82-Inch Reflector, McDonald Observatory

1960 Apr 16.21830

T	$9^h\ 17^m58^s.27$	$+16^\circ\ 28'\ 46''.1$
A	$+4''.32$	$+18''.13$
U	+ 4.45	+11.51
O	-11.63	+ 3.84

1960 Apr 16.22333

T	9 17 58.26	+16 28 46.0
A	+ 4.46	+17.87
U	+ 4.50	+11.62
O	-11.55	+ 3.82

1960 Apr 16.25493

T	9 17 58.24	+16 28 46.3
A	+ 4.36	+17.87
U	+ 4.52	+11.65
O	-11.88	+ 3.39

1960 Apr 16.25771

T	9 17 58.23	+16 28 46.0
A	+ 4.51	+17.67
U	+ 4.62	+11.57
O	-11.87	+ 3.70

1960 Apr 19.09591

T	9 17 55.93	+16 29 35.6
A	-15.10	-18.08
U	-24.22	+ 5.90
O	-11.65	-45.25

1960 Apr 19.09939

T	9 17 55.93	+16 29 35.7
A	-15.04	-18.19
U	-24.29	+ 5.68
O	-11.62	-45.28

1960 Apr 19.10286

T	9 17 55.92	+16 29 35.8
A	-15.05	-18.29
U	-24.49	+ 5.38
O	-11.56	-45.37

1960 Apr 19.10779

T	9 17 55.92	+16 29 35.8
A	-14.86	-18.20
U	-24.45	+ 5.27
O	-11.50	-45.35

1960 Apr 19.11084

T	9 17 55.90	+16 29 36.0
A	-14.63	-18.26
U	-24.51	+ 5.20
O	-11.50	-45.37

1960 Apr 19.11434

T	9 17 55.90	+16 29 36.1
A	-14.78	-18.37
U	-24.35	+ 5.02
O	-11.39	-45.41

1960 Apr 19.11744

T	9 17 55.84	+16 29 36.2
A	-14.76	-18.38
U	-24.37	+ 4.81
O	-11.50	-45.65

1961 Apr 5.15441

T	9 37 30.70	+14 58 45.5
M	+ 4.47	-36.42
A	+11.06	-17.27
U	+13.25	-12.59
O	+16.79	-53.82

1961 Apr 5.15763

T	9 37 30.67	+14 58 45.2
M(1)	+ 4.27	-35.93
A	+11.04	-17.04
U	+13.30	-12.51
O	+16.79	-53.61

1961 Apr 5.16101

T	$9^h\ 37^m30^s.67$	$+14^\circ\ 58'\ 45''.6$
M	$+5''.32$	$-36''.16$
A	+11.16	-16.96
U	+13.25	-12.45
O	+16.86	-53.45

1961 Apr 5.16448

T	9 37 30.63	+14 58 45.6
M	+ 5.27	-35.17
A	+11.14	-16.84
U	+13.33	-12.29
O	+16.78	-53.38

1961 Apr 5.19243

T	9 37 30.44	+14 58 45.7
M	+ 5.54	-35.08
A	+10.91	-15.63
U	+13.35	-11.30
O	+16.34	-52.45

1961 Apr 5.19891

T	9 37 30.44	+14 58 45.8
M	+ 5.75	-35.03
A	+11.19	-15.47
U	+13.40	-11.04
O	+17.56	-52.35

1961 Apr 7.22528

T	9 37 30.14	+14 58 45.6
M(1)	+16.34	+27.79
A	+19.73	+12.16
U	+ 6.26	+ 3.97
O	+34.99	+32.20

1961 Apr 7.23002

T	9 37 30.12	+14 58 45.6
M	+16.66	+27.83
A	+19.70	+12.37
U	+ 6.42	+ 3.80
O	+35.10	+32.31

1961 Apr 7.23535

T	9 37 30.10	+14 58 45.6
M(1)	+15.95	+27.79
A	+19.82	+12.78
U	+ 6.47	+ 3.80
O	+35.02	+32.52

1961 Apr 7.23925

T	9 37 30.07	+14 58 45.6
M	+15.95	+27.76
A	+19.93	+12.94
U	+ 6.55	+ 3.83
O	+35.08	+32.70

1962 Mar 27.27569

T	9 57 20.75	+13 18 42.1
M	- 7.48	-43.49
A	- 8.07	-25.79
U	+ 3.02	-26.22
O	- 8.21	+ 2.54

1962 Mar 27.27911

T	9 57 20.72	+13 18 42.4
M	- 7.37	-43.60
A	- 8.08	-25.97
U	+ 2.95	-26.10
O	- 8.23	+ 2.42

1962 Mar 27.28287

T	9 57 20.70	+13 18 42.4
M	- 7.24	-43.55
A	- 8.14	-26.18
U	+ 2.98	-26.03
O	- 8.15	+ 2.41

1962 Mar 27.28513

T	9 57 20.68	+13 18 42.5
M	- 7.06	-43.55
A	- 8.05	-26.17
U	+ 3.10	-25.80
O	- 8.21	+ 2.32

1962 Mar 27.30163

T	$9^h\ 37^m20^s.56$	$+13^\circ\ 18'\ 42''.2$
M	- 6.73	$-43''.57$
A	- 7.83	-26.64
U	+ 3.34	-25.31
O	- 8.20	+ 2.17

1962 Mar 27.30422

T	9 57 20.52	+13 18 43.2
M	- 6.63	-43.40
A(4)	- 7.88	-26.58
U	+ 3.25	-25.28
O	- 8.22	+ 2.20

1962 Mar 27.30644

T	9 57 20.52	+13 18 43.2
M	- 6.64	-43.43
A(4)	- 8.07	-26.35
U	+ 3.17	-25.68
O	- 8.22	+ 2.20

1962 Mar 27.32286

T	9 57 20.39	+13 18 43.8
M	- 5.84	-43.36
U	+ 3.38	-24.64
O	- 8.15	+ 2.01

1962 Mar 27.32614

T	9 57 20.35	+13 18 43.9
M	- 5.86	-43.35
A(4)	- 9.48	-27.53
U	+ 3.52	-24.58
O	- 8.13	+ 1.95

1962 Mar 27.32830

T	9 57 20.34	+13 18 44.0
M	- 5.97	-43.27
U	+ 3.58	-24.44
O	- 8.12	+ 1.95

1962 Mar 28.33171

T	9 57 12.59	+13 19 9.7
A	+ 4.93	-35.48
U	+ 5.32	- 3.68
O	- 6.35	- 3.65

1962 Mar 28.33414(3)

T	9 57 12.59	+13 19 9.7
A	+ 4.93	-35.41
U	+ 4.94	- 3.65
O	- 6.11	- 3.77

1962 Mar 28.33744(3)

T	9 57 12.53	+13 19 9.7
A	+ 5.30	-35.13
U	+ 5.18	- 3.58
O	- 6.19	- 3.54

1962 Mar 28.34024(3)

T	9 57 12.51	+13 19 10.1
A	+ 5.38	-35.10
U	+ 5.40	- 3.62
O	- 6.16	- 3.61

1962 Mar 28.34317(3)

T	9 57 12.50	+13 19 10.3
A	+ 5.34	-35.02
U	+ 5.42	- 3.49
O	- 6.34	- 3.68

1962 Mar 28.34525(3)

T	9 57 12.48	+13 19 10.4
A	+ 5.19	-35.06
U	+ 5.23	- 3.69
O	- 6.23	- 3.68

1962 Mar 29.22078

T	9 57 5.98	+13 19 22.0
A	+15.72	+10.24
U	+ 3.37	- 6.70
O	- 4.71	- 2.33

OBSERVATIONS AT 82-INCH REFLECTOR, McDONALD OBSERVATORY

1962 Mar 29.22436

T	9^h 57^m $5^s.96$	$+13°$ $19'$ $22''.0$
A	$+15''.67$	$+10''.55$
U	+ 3.32	− 6.62
O	− 4.49	− 2.24

1962 Mar 29.22772

T	9 57 5.92	+13 19 22.1
A	+15.57	+10.57
U	+ 3.24	− 6.61
O	− 4.48	− 2.62

1962 Mar 29.22934

T	9 57 5.89	+13 19 22.1
A(4)	+15.57	+10.70
U	+ 3.26	− 6.73
O	− 4.52	− 2.33

1962 Mar 29.23507

T	9 57 5.87	+13 19 22.1
A	+15.60	+10.78
O	− 4.46	− 2.32

1962 Mar 29.23744

T	9 57 5.84	+13 19 22.3
A	+15.43	+10.73
O	− 4.51	− 2.24

1962 Mar 29.28535

T	9 57 5.60	+13 19 22.2
A	+15.20	+12.68
O	− 4.46	− 2.09

1962 Mar 29.29358

T	9 57 5.44	+13 19 22.1
M(1)	+15.22	+ 7.07
A	+15.28	+14.84
U(4)	+ 3.77	− 5.22
O	− 4.39	− 2.34

1962 Mar 29.29925

T	9 57 5.39	+13 19 22.2
M	+15.24	+ 7.50
A	+15.36	+13.05
U(4)	+ 3.56	− 7.11
O	− 4.42	− 2.01

1962 Mar 29.30197(3)

T	9 57 5.37	+13 19 22.4
M(1)	+15.50	+ 7.50
A	+15.19	+13.18
U(4)	+ 3.67	− 7.20
O	− 4.45	− 1.80

1962 Mar 29.30411(3)

T	9 57 5.35	+13 19 22.4
M	+15.27	+ 7.61
A	+15.20	+13.16
U(4)	+ 3.67	− 7.36
O	− 4.44	− 1.77

1962 Apr 13.16347

T	9 55 42.84	+13 26 48.3
A	− 3.63	−21.90
U	− 1.73	−16.49
O	−26.96	−59.02

1962 Apr 17.16014

T	9 55 25.62	+13 27 3.3
A	+ 7.41	+14.28
U	+19.36	+40.08
O	+20.18	+ 3.04

1962 Apr 17.16604

T	9 55 25.66	+13 27 3.2
A	+ 7.30	+14.26
U	+19.58	+39.64
O	+19.97	+ 2.65

1962 Apr 17.17229

T	9^h 55^m $25^s.64$	$+13°$ $27'$ $3''.3$
A	$+ 7''.37$	$+14''.21$
U	+19.51	+39.88
O	+20.11	+ 2.81

1962 Apr 21.15153

T	9 55 14.72	+13 28 51.2
M	−13.22	−14.23
A	−11.32	− 8.15
U	− 4.73	−14.78
O	− 0.30	+19.72

1962 Apr 21.15471

T	9 55 14.72	+13 28 51.3
M	−13.35	−14.44
A	−11.44	− 8.13
U	− 4.75	−14.71
O	− 0.28	+19.67

1962 Apr 24.16342(3)

T	9 55 5.70	+13 29 8.4
U	+ 8.73	−26.82
O	+ 0.01	+13.25

1962 Apr 24.16864(3)

T	9 55 5.70	+13 29 8.4
U	+ 8.71	−26.66
O	− 0.16	+13.22

1962 Apr 24.17384

T	9 55 5.68	+13 29 8.3
U	+ 8.81	−26.47
O	− 0.21	+13.31

1962 Apr 24.17940

T	9 55 5.66	+13 29 8.1
U	+ 8.97	−26.20
O	− 0.10	+13.27

1962 Apr 25.15449

T	9 55 3.49	+13 28 53.9
M	+16.95	+24.16
A	+14.91	+ 5.11
U	+21.17	+19.00
O	−25.77	+16.57

1962 Apr 25.15773

T	9 55 3.47	+13 28 53.9
M	+17.10	+24.35
A	+15.18	+ 5.31
U	+21.21	+19.07
O	−25.90	+16.58

1962 Apr 25.16386

T	9 55 3.41	+13 28 53.8
M	+16.58	+24.52
A	+15.01	+ 5.61
U	+20.90	+19.36
O	−25.80	+16.58

1962 Apr 25.16745

T	9 55 3.46	+13 28 53.7
M	+16.88	+24.50
A	+15.24	+ 5.75
U	+21.29	+19.54
O	−26.08	+16.61

1962 Apr 26.17034

T	9 55 1.85	+13 28 46.0
A	+11.42	+45.14
U	+12.26	+50.84
O	− 8.29	+11.79

1962 Apr 26.17394

T	9 55 1.85	+13 28 46.0
A	+11.50	+45.17
U	+12.43	+50.78
O	− 8.19	+11.70

1962 Apr 26.17774

T	9^h 55^m $1^s.84$	$+13°$ $28'$ $46''.0$
A	$+11''.24$	$+45''.19$
U	+12.08	+50.94
O	− 8.46	+11.77

1962 Apr 26.18105

T	9 55 1.84	+13 28 46.0
A	+11.14	+45.10
U	+11.99	+50.87
O	− 8.48	+11.62

1964 May 28.18108

T	10 31 35.08	+10 6 16.1
U	− 2.97	−14.41
O	+ 7.16	+16.26

1964 May 28.18454

T	10 31 35.07	+10 6 16.1
U	− 2.89	−14.45
O	+ 7.21	+16.41

1964 May 29.12361

T	10 31 37.47	+10 5 39.7
A(5)	+ 4.14	− 0.22
U	− 2.08	−22.81
O	+ 9.27	+29.03

1964 May 30.12598

T	10 31 40.36	+10 4 55.5
A	+ 6.25	− 0.08
U	+ 8.14	− 1.19
O	+ 7.88	+39.15

1964 May 30.12818

T	10 31 40.36	+10 4 55.4
A	+ 6.28	− 0.12
U	+ 8.16	− 1.16
O	+ 8.01	+39.06

1964 May 30.13058

T	10 31 40.36	+10 4 55.3
A	+ 6.34	− 0.11
U	+ 8.08	− 1.03
O	+ 7.83	+39.13

1964 May 30.13298

T	10 31 40.37	+10 4 55.1
A	+ 6.42	+ 0.08
U	+ 8.21	− 0.89
O	+ 7.92	+39.19

1964 May 30.13611

T	10 31 40.38	+10 4 55.0
A	+ 6.60	+ 0.17
U	+ 8.24	− 0.74
O	+ 7.93	+39.04

1964 May 30.13819

T	10 31 40.38	+10 4 55.0
A	+ 6.55	+ 0.04
U	+ 8.27	− 0.77
O	+ 8.09	+39.04

1964 May 30.14051

T	10 31 40.40	+10 4 54.7
A	+ 6.49	+ 0.37
U	+ 8.32	− 0.55
O	+ 7.94	+39.25

1964 May 30.14254

T	10 31 40.40	+10 4 54.9
A	+ 6.52	+ 0.20
U	+ 8.38	− 0.72
O	+ 8.09	+39.05

1964 June 2.12535

T	10 31 51.83	+10 3 41.2
M	+ 1.57	+25.93
U	− 7.00	+ 6.36
O	−14.42	−12.89

OBSERVATIONS AT 82-INCH REFLECTOR, McDONALD OBSERVATORY

1964 June 2.12760

T	10^h	$31^m51^s.82$	$+10^\circ$	$3'$	$41''.5$
M		$+0^s.98$	$+25''.87$		
U		-7.19	$+6.41$		
O		-14.66	-12.82		

1964 June 2.12978

T	10	31 51.85	+10	3	41.7
M		+ 0.97	+25.73		
U		- 7.24	+ 6.14		
O		-14.62	-13.03		

1964 June 2.13226

T	10	31 51.84	+10	3	41.8
M		+ 1.07	+25.64		
U		- 7.24	+ 6.17		
O		-14.56	-12.99		

1964 June 2.13463

T	10	31 51.87	+10	3	42.0
M		+ 1.02	+25.56		
U		- 7.27	+ 5.76		
O		-14.60	-13.27		

1964 June 2.13701

T	10	31 51.86	+10	3	41.9
M		+ 1.28	+25.63		
U		- 7.22	+ 5.90		
O		-14.62	-13.15		

1964 June 2.13935

T	10	31 51.89	+10	3	41.8
M		+ 1.04	+25.57		
U		- 7.31	+ 5.60		
O		-14.67	-13.44		

1964 June 2.14208

T	10	31 51.87	+10	3	41.7
M		+ 1.08	+25.48		
U		- 7.34	+ 5.75		
O		-14.57	-13.23		

1964 June 2.14496

T	10	31 51.92	+10	31	41.8
M		+ 0.92	+25.44		
U		- 7.48	+ 5.31		
O		-14.86	-13.59		

1964 June 2.14754

T	10	31 51.91	+10	31	41.8
M		+ 0.82	+25.58		
U		- 7.48	+ 5.35		
O		-14.73	-13.69		

1964 June 2.15046

T	10	31 51.93	+10	31	41.6
M		+ 0.80	+25.41		
U		- 7.51	+ 5.34		
O		-14.78	-13.66		

1964 June 2.15301

T	10	31 51.94	+10	31	41.7
M		+ 0.85	+25.34		
U		- 7.50	+ 5.15		
O		-14.80	-13.74		

Measures With 61-Inch NASA Reflector

After the 61-inch reflector of the Lunar and Planetary Laboratory was put into operation on the Catalina Mountains in October 1965, a new series of plates of the Uranus satellites was obtained by the writer. The earth passed through the planes of the satellites' orbits, which were therefore seen edge on, early in 1966. On many nights some of the satellites were occulted by the planet. These plates were measured in the same way as the previous series, but there is a difference in the way the results are given: the coordinates of all the satellites are given in α and δ instead of giving these coordinates only for Titania with the differential coordinates for the other satellites. On many nights Titania was occulted by the planet so it could not be used as reference for the other satellites. Here again, it should be noted that while the uncertainties in the plate constants of the *Astrographic Catalogues* affect the precision of the equatorial coordinates, they hardly affect the differences between the positions.

In the hope of strengthening the observational data by referring the satellites to the planet, several partial gratings over the incoming light beam were tried in order to obtain two fainter diffraction images of the planet, the mean of which could be substituted for the planet itself in the measures. Unfortunately, it was found that the oval-shaped secondary images of the planet did not lend themselves to measures with a precision comparable to the settings on the sharp small satellite images. Further trials were therefore abandoned.

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OBSERVATIONS AT 61-INCH REFLECTOR, LUNAR AND PLANETARY LABORATORY

1966 Feb 14.35669

A	11^h	18^m	$15^s.00$	$+5^\circ$	$22'$	$16''.6$
U			14.88		22	7.0
T			15.67		22	47.2
O			14.54		21	51.2

1966 Feb 14.35912

A	11	18	15.05	+5	22	16.7
U			14.89		22	7.2
T			15.68		22	46.9
O			14.57		21	51.4

1966 Feb 14.36207

A	11	18	15.02	+5	22	17.0
U			14.86		22	6.6
T			15.63		22	47.0
O			14.54		21	51.8

1966 Feb 14.38290

A	11	18	14.82	+5	22	18.9
U			14.65		22	8.6
T			15.42		22	48.2
O			14.36		21	53.2

1966 Feb 14.38464

A	11	18	14.80	+5	22	19.1
U			14.62		22	8.6
T			15.40		22	48.3
O			14.30		21	53.0

1966 Feb 14.38626

A	11	15	14.84	+5	22	18.6
U			14.64		22	8.3
T			15.43		22	47.9
O			14.34		21	52.9

1966 Feb 17.24722

T	11	17	49.31	+5	24	38.6
O			50.15		25	27.9

1966 Feb 17.24896

T	11	17	49.31	+5	24	38.8
O			50.19		25	29.6

1966 Feb 17.25104

T	11	17	49.33	+5	24	38.6
O			50.19		25	29.7

1966 Feb 17.25382

T	11	17	49.33	+5	24	38.9
O			50.18		25	30.3

1966 Feb 17.25556

T	11	17	49.29	+5	24	38.8
O			50.16		25	30.6

1966 Feb 17.25764

T	11	17	49.27	+5	24	38.6
U			50.13		25	30.0

1966 Feb 19.33681

A	11	17	30.88	+5	27	3.5
U			31.93		27	59.3

1966 Feb 19.34132

A	11	17	30.84	+5	27	1.6
U			31.88		27	57.6

1966 Feb 19.34306

A	11	17	30.85	+5	27	1.7
U			31.86		27	57.3

1966 Feb 19.34514

A	11	17	30.83	+5	27	1.6
U			31.83		27	57.3

1966 Mar 29.26007

A	11^h	11^m	$32^s.42$	$+6^\circ$	$4'$	$46''.0$
U			32.79		5	6.8
T			33.13		5	24.5
O			32.79		5	5.0

1966 Mar 29.26250

A	11	11	32.40	+6	4	46.1
U			32.76		5	7.3
T			33.09		5	24.7
O			32.76		5	4.9

1966 Apr 12.20694

T	11	9	38.62	+6	16	15.4
O			39.24		16	48.1

1966 Apr 12.20937

T	11	9	38.60	+6	16	15.7
O			39.27		16	48.2

1966 Apr 12.21215

T	11	9	38.60	+6	16	15.8
O			39.20		16	48.3

1966 Apr 13.21736

A	11	9	30.95	+6	17	21.6
(3) U			30.83		17	15.2
(5) T			31.38		17	43.5
O			31.86		18	9.9

1966 Apr 13.22326

A	11	9	30.88	+6	17	21.9
(3) U			30.82		17	15.0
(5) T			31.30		17	43.9
O			31.78		18	10.3

1966 Apr 13.22639

A	11	9	30.87	+6	17	22.1
(3) U			30.82		17	14.7
(5) T			31.29		17	44.1
O			31.75		18	10.6

1966 Apr 13.22986

A	11	9	30.86	+6	17	22.5
(3) U			30.71		17	13.3
T			31.29		17	44.5
O			31.73		18	10.6

1966 Apr 13.23264

A	11	9	30.82	+6	17	22.5
(3) U			30.70		17	13.3
T			31.26		17	44.5
O			31.75		18	10.6

1966 Apr 13.23542

A	11	9	30.83	+6	17	22.7
(3) U			30.67		17	13.2
T			31.23		17	44.7
O			31.73		18	10.8

1966 Apr 14.17569

A	11	9	24.90	+6	18	10.5
(4) U			24.54		17	48.7
T			25.15		18	23.7
O			25.43		18	40.2

1966 Apr 14.17887

A	11	9	24.90	+6	18	10.7
(4) U			24.53		17	48.6
T			25.14		18	23.9
O			25.43		18	40.3

1966 Apr 14.18194

A	11	9	24.87	+6	18	10.7
(4) U			24.50		17	48.9
T			25.11		18	24.0
O			25.49		18	40.2

1966 Apr 14.18472

A	11^h	9^m	$24^s.84$	$+6^\circ$	$18'$	$10''.2$
T			25.10		18	23.5
O			25.39		18	39.8

1966 Apr 14.19028

A	11	9	24.80	+6	18	10.6
T			25.05		18	23.8
O			25.34		18	40.0

1966 Apr 14.19340

A	11	9	24.80	+6	18	10.6
T			25.03		18	23.9
O			25.32		18	40.0

1966 Apr 23.15937

A	11	8	26.71	+6	23	23.0
U			27.19		23	50.1
T			27.50		24	7.7
O			26.47		23	8.3

1966 Apr 23.16285

A	11	8	26.67	+6	23	23.2
U			27.18		23	50.2
T			27.49		24	7.8
O			26.46		23	8.1

1966 Apr 23.16840

A	11	8	26.63	+6	23	23.5
U			27.15		23	50.9
T			27.46		24	8.1
O			26.41		23	8.8

1966 Apr 23.17066

A	11	8	26.63	+6	23	23.3
U			27.15		23	50.4
T			27.45		24	8.2
O			26.42		23	8.7

1966 Apr 23.17257

A	11	8	26.65	+6	23	23.3
U			27.15		23	50.6
T			27.45		24	8.4
O			26.42		23	8.5

1966 Apr 25.16788

U	11	8	15.61	+6	24	32.4
T			16.07		25	59.8
O			16.08		24	52.5

1966 Apr 25.17222

U	11	8	15.60	+6	24	32.3
T			16.03		25	59.9
O			16.04		24	52.8

1966 Apr 25.17431

U	11	8	15.57	+6	24	32.3
T			16.03		25	59.7
O			16.04		24	52.7

1966 Apr 25.17691

U	11	8	15.54	+6	24	33.1
T			16.01		25	0.7
O			16.00		24	53.9

1966 Apr 25.17812

U	11	8	15.55	+6	24	33.1
T			16.03		25	0.8
O			16.02		24	53.7

1966 Apr 25.18056

U	11	8	15.57	+6	24	33.3
T			16.03		25	1.0
O			16.03		24	53.9

1966 May 9.22155

T	11	7	17.48	+6	30	28.1
O			17.67		30	37.2

OBSERVATIONS AT 61-INCH REFLECTOR, LUNAR AND PLANETARY LABORATORY

1966 May 9.22346

T	11^h	7^m	$17^s.47$	$+6^\circ$	$30'$	$28''.1$
O			17.68		30	37.3

1966 May 9.22485

T	11	7	17.49	+6	30	28.3
O			17.68		30	37.4

1966 May 9.23735

T	11	7	17.45	+6	30	28.3
O			17.67		30	37.5

1966 May 9.23856

T	11	7	17.45	+6	30	28.5
O			17.64		30	37.4

1966 May 9.23961

T	11	7	17.44	+6	30	28.7
O			17.64		30	37.3

1966 May 10.14390

U	11	7	15.05	+6	30	49.5
T			15.17		30	55.1
O			15.36		31	5.2

1966 May 10.14581

U	11	7	15.05	+6	30	49.5
T			15.18		30	55.0
O			15.36		31	5.2

1966 May 10.17745

U	11	7	14.98	+6	30	50.4
T			15.08		30	56.0
O			15.29		31	5.8

1966 May 10.17845

U	11	7	14.97	+6	30	50.4
T			15.08		30	55.9
O			15.28		31	6.1

1966 May 10.18001

U	11	7	14.96	+6	30	50.4
T			15.06		30	56.0
O			15.25		31	6.2

1966 May 11.21012

T	11	7	12.48	+6	31	17.6
O			12.69		31	28.0

1966 May 11.21376

T	11	7	12.47	+6	31	17.6
O			12.68		31	28.1

1966 May 11.21610

T	11	7	12.47	+6	31	17.7
O			12.68		31	28.3

1966 May 11.22088

T	11	7	12.43	+6	31	17.8
O			12.63		31	28.3

1966 May 11.22366

T	11	7	12.42	+6	31	17.6
O			12.62		31	28.0

1966 May 11.23199

T	11	7	12.42	+6	31	17.9
O			12.63		31	28.4

1966 May 12.13993

A	11	7	9.93	+6	31	12.6
U			9.35		30	41.0
T			10.09		31	23.6
O			10.43		31	41.0

1966 May 12.14371

A	11^h	7^m	$9^s.94$	$+6^\circ$	$31'$	$12''.7$
U			9.35		30	41.1
T			10.10		31	23.7
O			10.45		31	41.1

1966 May 12.14429

A	11	7	9.95	+6	31	12.7
U			9.36		30	41.0
T			10.11		31	23.6
O			10.44		31	41.2

1966 May 12.14618

A	11	7	9.91	+6	31	12.8
U			9.33		30	41.2
T			10.07		31	23.9
O			10.41		31	41.3

1966 May 12.14740

A	11	7	9.90	+6	31	12.8
U			9.32		30	41.1
T			10.06		31	24.0
O			10.41		31	41.3

1966 May 12.14929

A	11	7	9.90	+6	31	13.0
U			9.32		30	41.1
T			10.06		31	23.9
O			10.39		31	41.5

1966 May 13.13733

A	11	7	7.20	+6	30	55.5
U			7.35		31	0.5
O			8.07		31	1.4

1966 May 13.13958

A	11	7	7.21	+6	30	55.6
U			7.35		31	0.3
O			8.08		31	1.2

1966 May 13.14167

A	11	7	7.22	+6	30	55.8
U			7.34		31	0.2
O			8.08		31	1.0

1966 May 13.14392

A	11	7	7.22	+6	30	55.5
U			7.34		31	0.4
O			8.06		31	1.2

1966 May 13.14583

A	11	7	7.20	+6	30	55.5
U			7.34		31	0.5
O			8.06		31	1.2

1966 May 13.14809

A	11	7	7.20	+6	30	55.4
U			7.36		31	0.5
O			8.05		31	1.1

1966 May 24.14483

U	11	6	55.49	+6	31	42.1
T			55.15		31	19.8
O			56.43		32	31.4

1966 May 24.14760

U	11	6	55.51	+6	31	42.2
T			55.14		31	19.8
O			56.44		32	31.5

1966 May 24.15021

U	11	6	55.50	+6	31	42.4
T			55.15		31	19.9
O			56.43		32	31.5

MEASURES OF MARS' SATELLITES BY G. VAN BIESBROECK ON PLATES TAKEN IN 1956 AT THE CASSEGRAIN FOCUS OF THE 82-INCH MCDONALD REFLECTOR, BY G. P. KUIPER

U.T.		Phobos (1900.0) α			δ			(Deimos − Phobos) (1900) x	y
1956 Sept	5.27028	23^h	28^m	$55^s.55$	-10°	$1'$	$31''.1$	$-6''.50$	$-27''.63$
	5.27751		28	55.13		1	31.2	−5.30	−28.88
	5.28735		28	54.51		1	31.6	−2.84	−29.54
	6.22230		27	55.91		6	9.1	−102.31	−42.49
	6.22549		27	55.75		6	9.1	−102.94	−43.42
	6.23307		27	55.33		6	9.1	−103.69	−46.78
	6.23741		27	55.06		6	9.0	−103.48	−48.10
	6.24175		27	54.80		6	9.2	−103.39	−49.63
	6.26501		27	53.05		6	10.9	−98.14	−56.60
	6.26796		27	52.80		6	11.3	−96.58	−57.08
	6.27317		27	52.31		6	12.3	−94.00	−58.07
	6.28376		27	51.32		6	14.9	−87.88	−59.40
	6.28584		27	51.11		6	15.0	−86.65	−59.61
	6.28723		27	50.91		6	15.6	−85.44	−59.74
	6.29748		27	49.92		6	18.2	−78.45	−60.13
	10.18817		23	35.80		24	12.2	−6.83	−43.42
	10.21282		23	33.36		24	25.7	+11.72	−33.28
	10.21620		23	33.08		24	27.4	+13.81	−31.99
	10.23765		23	31.36		24	38.8	+24.18	−23.70
	10.24025		23	31.20		24	40.0	+25.08	−22.86
	12.34429		21	14.50		32	41.8	−88.20	−21.37
	12.34670	23	21	16.28	−10	32	41.3	−87.87	−21.94

No. 146 THE ORBIT OF COMET BURNHAM-SLAUGHTER 1958e-1959I

by G. Van Biesbroeck

ABSTRACT

Using 94 observations covering an interval of 592 days, a preliminary set of parabolic elements was improved differentially, taking into account the perturbations by all the planets from Venus to Neptune. The final solution yields a very nearly parabolic ellipse. Backward and forward computations of the perturbations over 20 year intervals show that the comet is a permanent member of the solar system.

This comet was discovered September 7, 1958, (1958) with the 13-inch telescope of the Lowell Observatory by Robert Burnham, Jr., and Charles D. Slaughter in the course of the proper motion survey. This was the third comet found by Burnham, who had previously found Comet 1958*a* and who was co-discoverer of Comet 1957*f*. The new comet, a diffuse object of magnitude 14, showed a centrally condensed nucleus in an asymmetrical coma extending 30″ into a fan-shaped tail toward the southeast. On September 14 Miss E. Roemer noticed a well-condensed, but distinctly not stellar, nucleus of magnitude 17. The comet slowly brightened and the tail extension turned clockwise, pointing toward position angle 50° on December 2. In the first days of 1959 the comet presented itself as a diffuse coma of total magnitude 13.5 still elongated in the first quadrant. The nearly stellar nucleus had then reached magnitude 15.8. Maximum brightness occurred in March 1959, when I described the comet as a round coma, centrally condensed and of total magnitude 13 (March 13), while Beyer called the magnitude 11.1 on March 11. As the comet moved into the evening sky, it was followed at low altitude until June 2, the total magnitude being 14 at that time. After conjunction with the sun, the object was picked up in the morning sky on December 4, 1959, by Roemer who then called the magnitude 19.5. This assiduous observer recorded the receding comet for several months more until April 21, 1960, when the magnitude had dropped to 19.7 This extended the duration of visibility to 592 days. Preliminary elements were deduced by M. P. Candy (1958a) and Roemer (1958). From a longer arc covering the period September 7 to November 4, Candy (1958b) computed the following elements:

Perihelion 1959 Mar. 11.52737 ET

$$\left.\begin{aligned} \omega &= 100\overset{\circ}{.}7341 \\ \Omega &= 323\overset{\circ}{.}0806 \\ i &= 61\overset{\circ}{.}2588 \end{aligned}\right\} 1950.0$$
$$q = 1.628380$$

which did not show an appreciable deviation from the parabola. This orbit proved to be a very good approximation for the whole duration of visibility and corrections to it were found for the final solution.

Table I gives the residuals from this orbit. A number of positions that were obviously in error were ignored. Not utilized were the measures by Waterfield at Ascot, nor those of Raudsaar at Tartu, which proved to be of very low weight. Roemer's positions were given weight 2. All the others were given weight 1 in deriving the normal places (Table II).

The perturbations by all the planets except Mercury and Pluto were computed in 20 day intervals taking 1959 July 1 as date of osculation. The values transformed in equatorial coordinates and interpolated for the dates of the normal places are given in Table II.

The coefficients of the equations of condition were completed according to Stracke's (1929) form.

TABLE I

Residuals O - C

	UT	Δα	Δδ	Ob*
1958				
Sept	11.227	$-0^{s}.11$	$-1''.8$	G
	12.140	-0.18	-1.3	V
	13.063	-0.21	+1.5	V
	13.780	-0.22	+1.6	A
	14.246	-0.22	+0.8	R
	14.276	-0.23	-1.0	R
	14.786	-0.25	+1.9	A
	15.101	-0.22	0.0	V
	15.292	-0.24	-0.2	R
	15.311	-0.22	-0.1	R
	15.974	-0.05	+1.1	A
	16.242	-0.24	+1.9	G
	19.072	-0.30	-0.8	V
	20.212	-0.38	-1.7	G
	20.234	-0.28	+1.0	R
	20.252	-0.32	+1.1	R
	21.284	-0.30	+0.6	R
	21.293	-0.30	0.0	R
Oct	4.175	0.00	+1.1	R
	4.181	+0.02	-0.7	R
	9.904	+0.09	-0.2	A
	10.895	-0.03	+3.6	A
	11.734	+0.27	-0.5	A
Oct	29.022	-0.42	+1.1	V
	29.715	-0.02	+0.7	A
	29.791	-0.16	-0.7	A
	30.006	-0.14	+0.5	V
	30.012	+0.07	+0.6	V
	30.745	+0.15	+0.9	A
	31.993	+0.01	+0.3	V
Nov	4.119	+0.10	+0.8	R
	4.158	+0.03	0.0	R
	10.056	+0.02	-0.6	R
	10.112	+0.03	-0.5	R
	11.059	+0.19	+0.8	V

	UT	Δα	Δδ	Ob
1958				
Nov	19.038	$+0^{s}.16$	$-1''.3$	V
	20.991	+0.02	+1.7	V
	26.999	+0.85	-1.1	V
	27.004	+0.78	-0.1	V
	27.697	+0.39	-0.7	A
	28.678	+0.44	-1.9	A
	28.981	+0.73	+1.3	V
	29.692	+0.15	-0.1	A
Dec	2.017	+0.33	-0.5	V
	2.115	+0.29	+0.3	R
	2.121	+0.30	+0.7	R
	2.741	+0.87	+2.5	A
	3.692	+0.32	+0.2	A
	3.788	+0.55	+1.3	A
	4.686	+0.14	-1.1	A
	5.985	-0.04	+1.3	V
	8.695	+0.33	+1.1	A
	9.046	+0.69	+0.8	V
	9.993	+0.22	-2.6	V
	11.987	+0.50	-4.7	V
1959				
Jan	4.998	+0.91	+1.1	V
	6.007	+0.39	+0.6	V
	10.004	+0.87	+2.3	V
	12.063	+0.34	+2.0	R
	12.091	+0.84	+6.2	R
Jan	31.038	+1.49	+1.8	V
Feb	1.077	+1.34	+1.4	R
	1.104	+1.38	+0.6	R
	2.929	+1.69	+0.9	V
	6.078	+1.67	+3.2	R
	6.084	+1.67	+3.6	R
	7.004	+1.50	+4.1	V
Feb	28.075	+2.69	+1.4	VM

	UT	Δα	Δδ	Ob
1959				
Mar	4.096	$+3^{s}.06$	$+0''.2$	R
	11.047	+3.78	+0.8	V
	12.053	+3.39	-0.2	V
	13.068	+3.19	+1.7	V
Apr	5.112	+4.53	-18.4	V
	6.117	+4.46	-19.6	V
	15.836	+4.03	-36.4	A
	15.854	+5.16	-26.2	A
Apr	29.127	+2.47	-37.9	R
	29.133	+2.50	-37.8	R
May	26.151	+0.62	-18.7	R
	26.159	+0.60	-18.5	R
June	2.110	+0.68	+16.3	V
	3.135	+0.39	+22.7	V
Dec	4.463	+0.25	-53.5	R
Dec	30.399	+0.24	-52.5	R
	30.474	+0.18	-52.3	R
1960				
Jan	24.314	+0.74	-52.6	R
	30.347	+0.42	-50.4	R
	30.420	+0.51	-49.9	R
Feb	21.219	+0.35	-49.3	R
	21.290	+0.16	-48.3	R
Mar	20.142	-0.17	-40.6	R
	20.241	-0.05	-40.9	R
Apr	17.205	-0.37	-36.7	R
Apr	21.156	-0.34	-37.0	R

* Observatories and Observers:

A Skalnate Pleso - Antal
G Lowell Observ. - Flagstaff - Giclas
R Naval Observ. - Flagstaff - Roemer
V Yerkes Observ. - Van Biesbroeck
VM MacDonald Observ. - Van Biesbroeck

TABLE II

Normal Places

UT			Weight	Perturbations		To be Corrected		Final Residuals	
	$\Delta\alpha\cos\delta$	$\Delta\delta$		$\Delta\alpha\cos\delta$	$\Delta\delta$	$\Delta\alpha\cos\delta$	$\Delta\delta$	$\Delta\alpha\cos\delta$	$\Delta\delta$
1958 Sept 16.0	- 4″3	+ 0″3	26	+12″0	-1″6	-16″3	+ 1″9	-0″2	+1″0
Oct 6.0	+ 0.9	+ 0.5	7	+10.4	-1.5	- 9.5	+ 2.0	+0.7	+1.3
Nov 3.0	+ 1.6	+ 0.2	16	+ 8.7	-1.4	- 7.1	+ 1.6	-0.9	-0.2
Nov 26.0	+ 3.2	- 0.3	8	+ 7.2	-1.4	- 4.0	+ 1.1	+1.0	-0.8
Dec 5.0	+ 5.4	- 0.2	14	+ 6.7	-1.4	- 1.3	+ 1.2	+0.9	-0.3
1959 Jan 9.5	+ 8.5	+ 2.9	7	+ 5.1	-1.7	+ 3.4	+ 4.6	-0.8	-0.7
Feb 2.4	+18.1	+ 2.8	11	+ 4.0	-2.4	+14.1	+ 5.2	+1.1	+0.8
Mar 4.0	+31.4	+ 0.7	6	+ 2.0	-2.6	+29.4	+ 3.3	+0.8	+1.2
Apr 11.1	+35.4	-25.0	4	- 0.6	-1.6	+36.0	-23.4	-0.2	2.1
Apr 29.1	+21.4	-37.8	4	- 0.8	-1.1	+22.2	-36.7	+1.1	-0.6
May 26.2	+37.8	-18.6	4	- 0.5	-0.1	+38.3	-18.5	+1.9	+0.2
Jun 2.5	+ 6.1	-19.5	2	- 0.2	0.0	+ 6.3	-19.5	-2.8	+2.1
Dec 4.5	+ 3.1	-53.5	2	- 2.3	+0.5	+ 5.4	-54.0	-0.4	-1.1
Dec 30.4	+ 3.1	-52.5	4	- 3.6	+1.1	+ 6.7	-53.6	-2.0	-1.7
1960 Jan 29.2	+ 8.4	-51.0	6	- 5.5	+1.6	+13.9	-52.6	+0.8	-1.5
Feb 21.2	+ 3.7	-48.8	4	- 7.4	+2.1	+11.1	-50.9	0.0	+1.9
Mar 20.2	- 1.1	-40.8	4	- 8.9	+2.6	+ 7.8	-43.4	0.0	+0.9
Apr 17.2	- 5.3	-36.7	2	- 8.9	+3.1	+ 3.6	-39.8	-0.5	+0.5
Apr 21.2	- 4.9	-37.0	2	- 9.0	+3.1	+ 4.1	-40.1	+0.1	-0.5 .

For that purpose the ecliptical elements were transformed into the following equatorial ones:

$$\left.\begin{aligned} \omega &= 86^\circ\ 43'\ 0''\!.92 \\ \Omega &= 327\ \ 44\ \ 24.96 \\ i &= 80\ \ 39\ \ 46.13 \end{aligned}\right\}\ 1950.0$$

The least squares solution performed on the IBM computer of the University of Arizona gave the following corrections of the equatorial elements:

$$\begin{aligned} \Delta\omega &= +9''\!.29 && \pm 0''\!.21 \\ \Delta\Omega &= -5.43 && \pm 0.10 \\ i &= -21.52 && \pm 0.17 \\ e &= -0.0002276 && \pm 0.0000030 \\ q &= -0.0001369 && \pm 0.0000007 \\ T &= -0.01026 && \pm 0.00014 \end{aligned}$$

The corresponding final ecliptical elements are:

$$T = 1959\ \text{Mar}\ 11.51711\ \text{ET}$$

$$\left.\begin{aligned} \Omega &= 323^\circ\!.07730 \\ i &= 61^\circ\!.25119 \\ \omega &= 100^\circ\!.73800 \end{aligned}\right\}\ 1950.0$$

$$e = 0.9997724$$

$$q = 1.628243$$

The last column of Table II shows the representation of the normal places. The mean error of a position of unit weight comes out 2″7. The small mean error of the eccentricity establishes with certainty the elliptic character of the orbit, but the period comes out of the order of a million years. Backward and forward computations of the inverse major axis were performed through the kind cooperation of Dr. B. Marsden with the following result for the barycentric values of $1/a$:

1939 Apr. 7	+ 0.0001025	($r = 39.8$ a.u.)
1979 Feb. 16	+ 0.0002715	($r = 39.7$ a.u.)

Acknowledgment. Support of this work by the National Science Foundation under Contract No. GP-11177 is hereby gratefully acknowledged.

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No. 147 THE ORBIT OF COMET HUMASON 1960e-1959X

by G. VAN BIESBROECK

ABSTRACT

Preliminary elements of this distant, faint comet were differentially corrected using 34 measures covering a period of 349 days. The orbit comes out very slightly hyperbolic but backward and forward computations show that the comet is a permanent member of the solar system.

Comet 1960*e* was discovered by M. L. Humason (1960) on a plate taken June 18, 1960, with the 48-inch Schmidt telescope of the Palomar Observatory. It appeared as a 17th magnitude centrally condensed diffuse coma with a short tail. On a 60-minute exposure on June 27 Miss E. Roemer, Flagstaff, noticed that the faint broad tail extended to 5′ southeast from the nucleus. At the time of discovery, this object proved to be at a distance of more than 4 astronomical units from both the earth and the sun and 6 months past perihelion. During the following months, the coma gradually faded while the nucleus remained sharp. Being no brighter than 18th magnitude, the comet was followed only by two observers, the writer at the Yerkes Observatory (1962) and, more extensively, Roemer (1966) at Flagstaff. She succeeded in recording the comet as long as 350 days after the first measure, when the brightness had dropped to 20th magnitude. M. P. Candy (1960) computed an orbit based on a 40-day arc which I used as a basis for the definitive orbit (Table I). Table II gives the residuals O–C for the 34 measures. These were combined in 12 normal places given in Table III.

TABLE I

Starting Ecliptical Elements

$$T = 1959 \text{ Dec } 12.54398 \text{ ET}$$
$$\left.\begin{aligned} \omega &= 46^\circ\!.7718 \\ \Omega &= 306.6347 \\ i &= 125.4774 \end{aligned}\right\} 1950$$
$$q = 4.274397 \text{ a.u.}$$

The planetary perturbations were computed in 20-day intervals and interpolated for the normal dates. All the planets except Mercury and Pluto were included. The date December 2, 1960, near the middle of the interval of observation, was chosen as the osculation point. As was to be expected from an object so distant from the sun and moving in a highly inclined retrograde orbit, the perturbations (Table III) proved to be very small.

The ecliptical elements were transformed into equatorial ones (Table IV) to compute the equations of condition in the form given by G. Stracke (1929).

Although the observations extend over nearly a year, the mean anomaly changed only from 29° to 66° and the solution from such a small arc remained necessarily not too well determined.

TABLE II

Residuals O - C

UT		Δα	Δδ	Observer
1960	June 23.20	-0^{s}.29	+0″.5	R
	23.25	-0.36	+1.0	R
	24.11	-0.99	-1.7	V
	24.12	-0.27	-0.2	V
	25.14	-0.37	-1.1	V
	26.15	-0.45	-2.1	V
	27.24	-0.63	+0.3	R
	27.25	-0.44	+0.9	R
	30.30	-0.48	-0.4	R
	June 30.32	-0.49	-0.5	R
	July 13.22	-0.44	+0.1	R
	21.14	-0.63	-2.7	V
	22.12	-0.60	-1.4	V
	24.11	-0.41	+1.5	V
	25.16	+0.14	+3.1	V
	July 28.11	-0.34	+1.7	V
	Aug 2.28	-0.01	-0.4	R
	Aug 2.29	+0.01	+0.4	R
	Aug 17.15	+0.72	+2.3	R
	Aug 17.18	+0.78	+3.0	R
1960	Sept 25.09	+2^{s}.17	+9″.2	R
	Sept 25.11	+2.15	+8.8	R
	Oct 22.07	+2.87	+18.5	R
	Dec 26.47	+5.01	+33.7	R
1961	Jan 17.40	+6.17	+35.7	R
	Jan 17.47	+6.22	+37.3	R
	Mar 23.27	+12.47	+37.4	R
	Mar 23.34	+12.56	+33.5	R
	Apr 9.15	+14.23	+42.2	R
	Apr 9.22	+14.36	+43.0	R
	May 9.35	+16.06	+69.8	R
	May 14.39	+16.69	+72.1	R
	June 7.21	+16.60	+91.2	R
	June 7.31	+16.51	+92.2	R

TABLE III

Normal Places

UT		Residuals		Weight	Perturbations		To be Corrected		Final Residuals	
		Δαcosδ	Δδ		Δαcosδ	Δδ	Δαcosδ	Δδ	Δαcosδ	Δδ
1960	June 26.11	- 4″.4	- 0″.4	10	+2″.4	-2″.0	- 6″.8	+ 1″.6	+0″.1	+0″.4
	July 22.31	- 4.4	+ 0.6	6	+1.2	-1.2	- 5.6	+ 1.8	-1.3	+0.2
	Aug 2.28	0.0	0.0	2	+1.0	-0.9	- 1.0	+ 0.9	-0.4	-1.1
	Aug 17.16	+ 9.0	+ 2.6	2	+0.6	-0.7	+ 8.4	+ 3.3	+2.8	-0.7
	Sept 25.10	+ 27.3	+ 9.0	2	+0.2	-0.3	+ 27.1	+ 9.3	+3.3	-2.4
	Oct 22.07	+ 36.9	+18.5	1	+0.1	-0.1	+ 36.8	+18.6	+1.0	+0.1
	Dec 26.47	+ 62.8	+33.7	1	0.0	0.0	+ 62.8	+33.7	-1.7	+0.6
1961	Jan 17.43	+ 74.9	+36.5	2	+0.1	-0.1	+ 74.8	+36.6	-0.8	+1.6
	Mar 23.30	+123.8	+35.4	2	+0.5	-0.2	+123.3	+35.6	+1.4	-0.8
	Apr 9.18	+135.2	+42.6	2	+0.6	-0.1	+134.6	+42.7	-0.7	-1.1
	May 11.87	+152.5	+71.0	2	+0.3	0.0	+152.2	+71.0	-1.8	+1.3
	June 7.26	+161.4	+91.7	2	0.0	0.0	+161.4	+91.7	+1.0	+0.6

The solution of the equations of condition was obtained on the IBM computer of the University of Arizona. The corrections to the elements and mean errors are:

$$\Delta T = -1^{d}18428 \pm 0^{d}001621$$
$$\Delta\omega = -16' 10''73 \pm 1''93$$
$$\Delta\Omega = -3' \; 21''63 \pm 0''31$$

$$\Delta i = -1' 44''72 \pm 0''12$$
$$\Delta e = +0.0000400 \pm 0.0000109$$
$$\Delta q = -0.0065290 \pm 0.0000245 \text{ a.u.}$$

The new elements, therefore, become:

T 1959 Dec 11.35975 ET
q 4.2678680 a.u.
e 1.0000400

	Equatorial	Ecliptical
ω	18°50′51″15	46°30′31″81 = 46°508837
Ω	288 8 47.95	306 34 34.38 = 306.576217
i	136 30 24.49	125 28 10.22 = 125.469506

In the last column of Table III are given the final residuals, which prove to be as satisfactory as can be expected.

The hyperbolic excess of the eccentricity comes out four times its probable error. It is of interest to find out what is the character of the original and future orbit.

Through the kind cooperation of B. G. Marsden, the past and future perturbations by the planets from Mercury to Pluto were established on the CDC 6400 computer of the Smithsonian Astrophysical Observatory in Cambridge, Mass., with the result for $1/a$:

Osculating (1960 Dec. 2)	−0.0000094 ± 0.0000026
Barycentric original 1927 Apr. 30 $r = 53.4$ a.u.	+0.0001169
Barycentric future 1985 Jan. 5 $r = 44.3$ a.u.	+0.0000733

It therefore appears that the original as well as the future orbit turns out to be slightly elliptical.

TABLE IV

Equatorial Elements

$$\left.\begin{array}{lcl} \Omega & = & 288^\circ\ 12'\ 9''58 \\ \omega & = & 19\quad 7\ 1.88 \\ i & = & 136\quad 32\ 9.21 \end{array}\right\} 1950$$

Acknowledgment. Support of this work by the National Science Foundation under Contract GP-6615 is hereby gratefully acknowledged.

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No. 148 MARS — 1967 PHOTOGRAPHIC MAP

by STEPHEN LARSON

May 27, 1969

ABSTRACT

A map of Mars was constructed based on photographs taken with the 154 cm NASA telescope of the Catalina Observatory from March 15 to May 20, 1967. Photographs covering 6000 to 8900 Å were used to optimize seeing and minimize the reduction of contrast by the Martian atmosphere.

Good photographic coverage of Mars during the 1967 opposition, March 15 to May 20, was obtained with the NASA 154 cm telescope of the Catalina Observatory by Fountain, McLean and Larson. This presented the opportunity to produce a map (Figs. 2–3) which serves as a base for plotting cloud motions and other Martian atmospheric phenomena and by which surface changes may be detected in future oppositions.

More than 130 rolls of 35 mm film were taken during the opposition. Only a few frames were used here and a more complete series will be presented at a later date. Only red and near-infrared photographs (6000 to 8900Å) were used for the map so that contrast reduction by the Martian atmosphere was minimized. Good-quality photographs taken with Kodak High Speed Ektachrome were copied on film with a Wratten 25 filter to correspond to red exposures. Composites of 2 - 12 images were made which reduces the chance of displacements due to poor atmospheric seeing. The Mars prints were more than 6 cm in diameter and care was

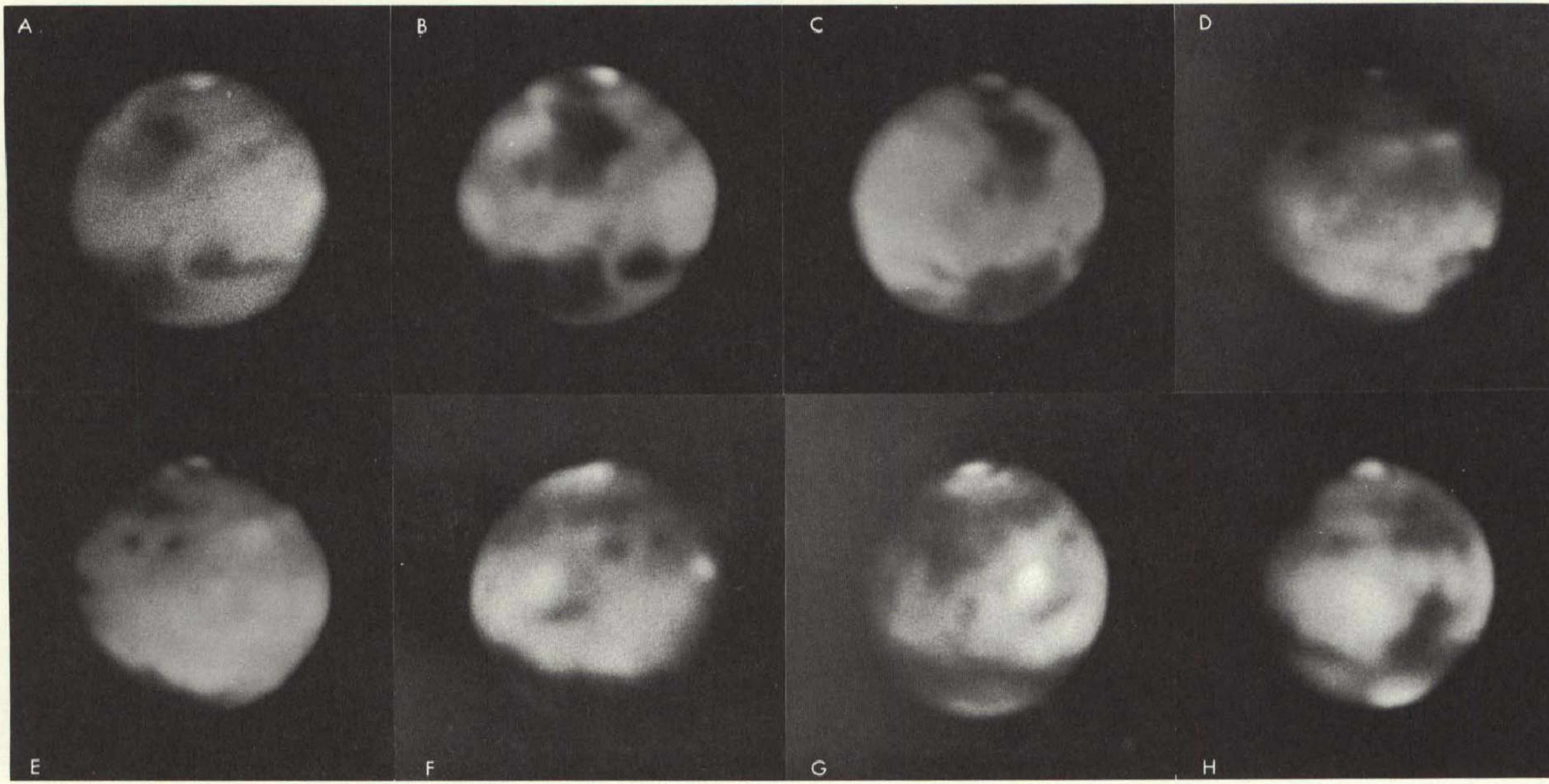

Fig. 1 Representative selection of photographs obtained during the 1967 opposition of Mars.

	Date	Time	Long. of C.M.		Date	Time	Long of C.M.
A)	1967, May 5	3:53.9 UT	8°3	E)	1967, April 26	8:58.8 UT	161°6
B)	1967, May 4	6:34.5 UT	56.5	F)	1967, March 15	9:59.1 UT	186.6
C)	1967, May 4	6:59.2 UT	62.4	G)	1967, May 20	5:43.7 UT	243.0
D)	1967, April 26	8:20.3 UT	152.3	H)	1967, May 15	6:44.4 UT	321.3

taken to keep their contrast uniform.

To achieve accurate positioning, a large grid was drafted with the appropriate tilt of 22°, photographed, and copied at the scale of the Mars prints. The grid was oriented with the aid of several points whose positions have been well established on the ACIC Mars map (MEC-2, 1967) and the North American Aviation, Inc. map "The Planet Mars" (1962). This simple method proved to be usually consistent to within 2° of areographic latitude from image to image. In the polar zone ($> 70°$N) the accuracy may be less.

A Mercator projection was used for latitudes 60°N to 60°S and a polar projection for the north polar region. Because of the planet's orientation, the region from 40°S to 90°S could not be reliably mapped.

For Martian nomenclature, reference is made to *Transactions,* International Astronomical Union (1958).

The map was first drawn in pencil at a scale of 1:25,000,000 with emphasis on accurate positioning of markings. Foreshortening effects were minimized by using only the central parts of the image, up to about 60° from the center. The final map was an airbrush tracing of this version by Mrs. B. Vigil, with special effort made to relate intensities accurately.

The accompanying photographs are representative of the material used.

Acknowledgments. I am indebted to Mrs. B. Vigil for her airbrush work on the map and to Mr. J. Fountain for making the data available for this work. This research was supported by NASA NGL03–002–002.

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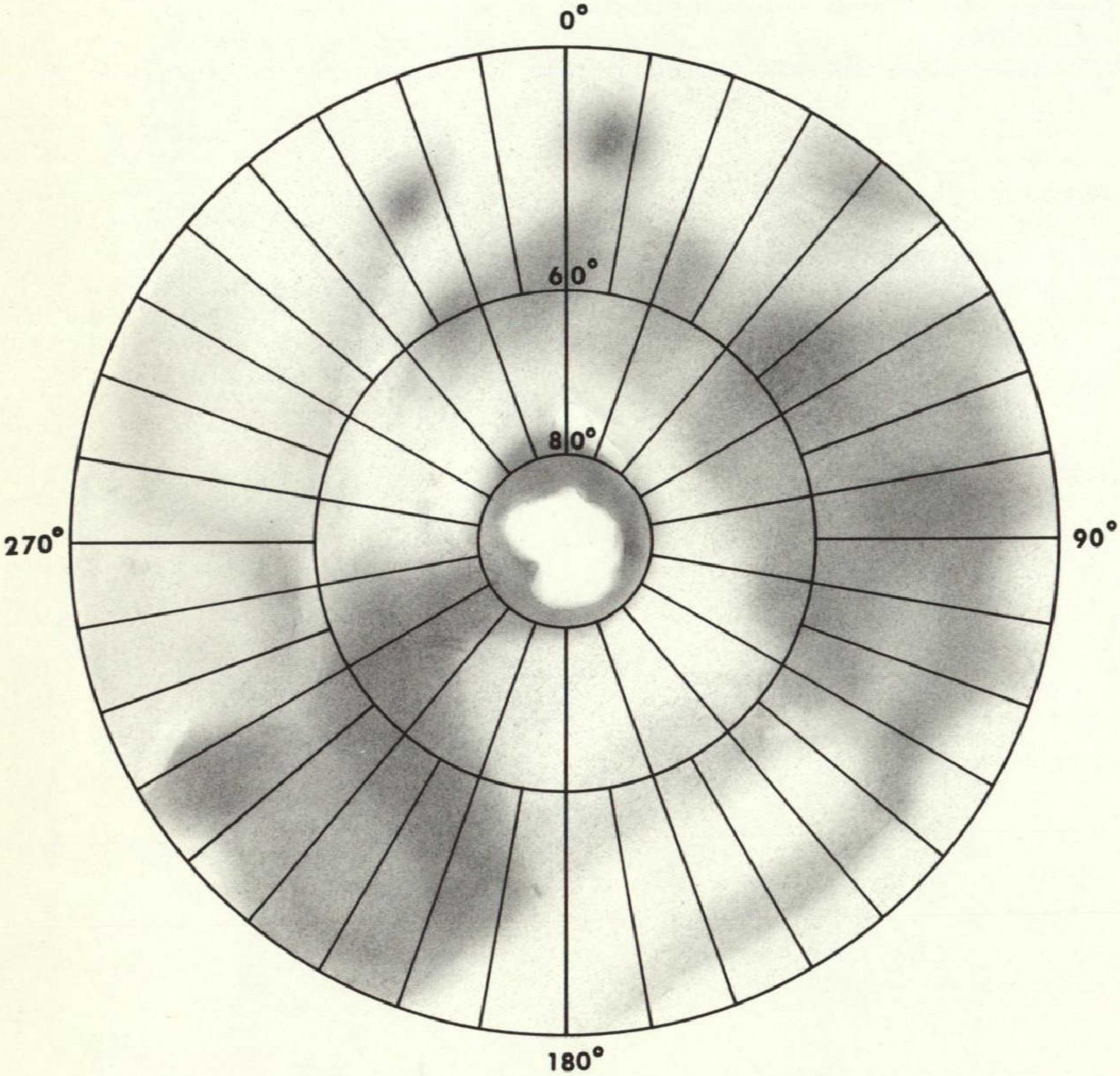

Fig.2 Map of Martian North Polar Region.

ERRATUM

Inadvertently the half-tones of Figs. 2 and 3 were rotated 180° in the printing.

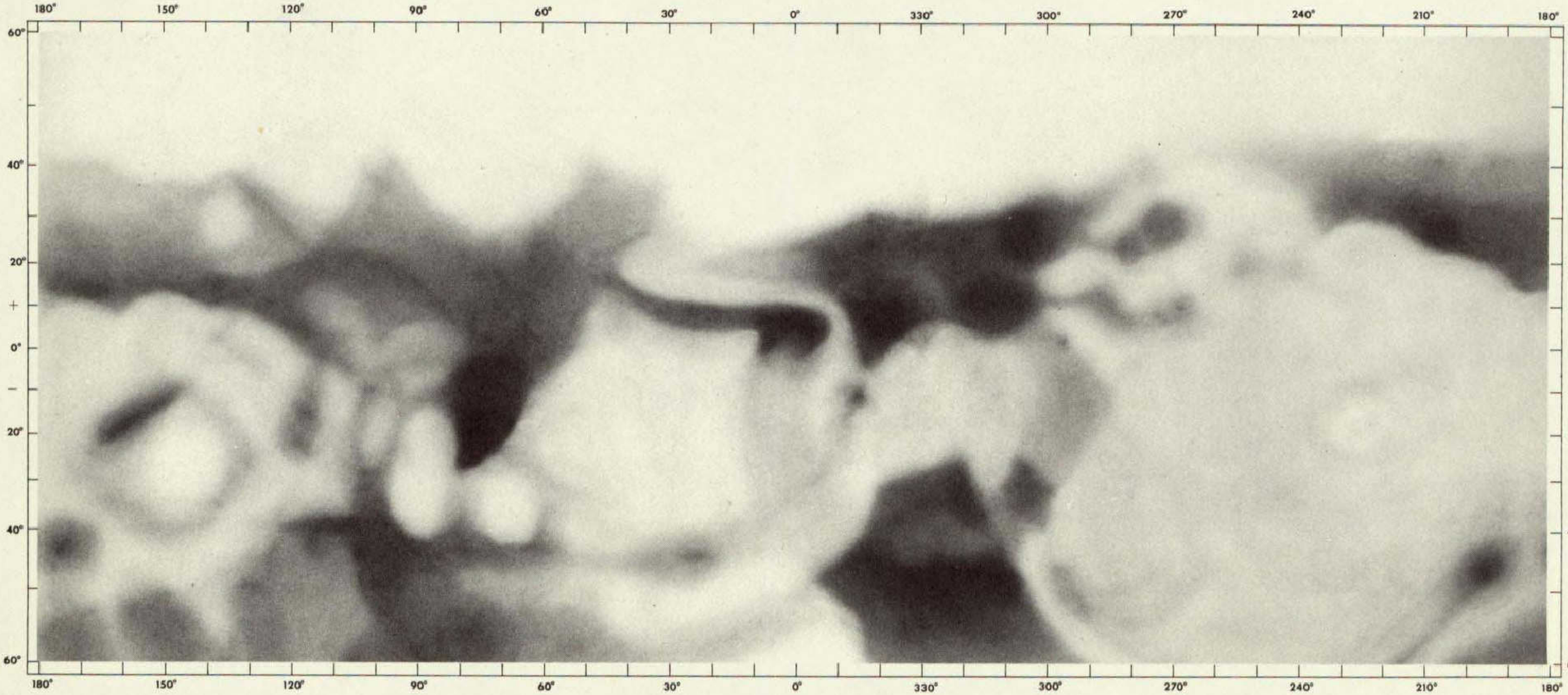

Fig. 3 Mars Map. North up.

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